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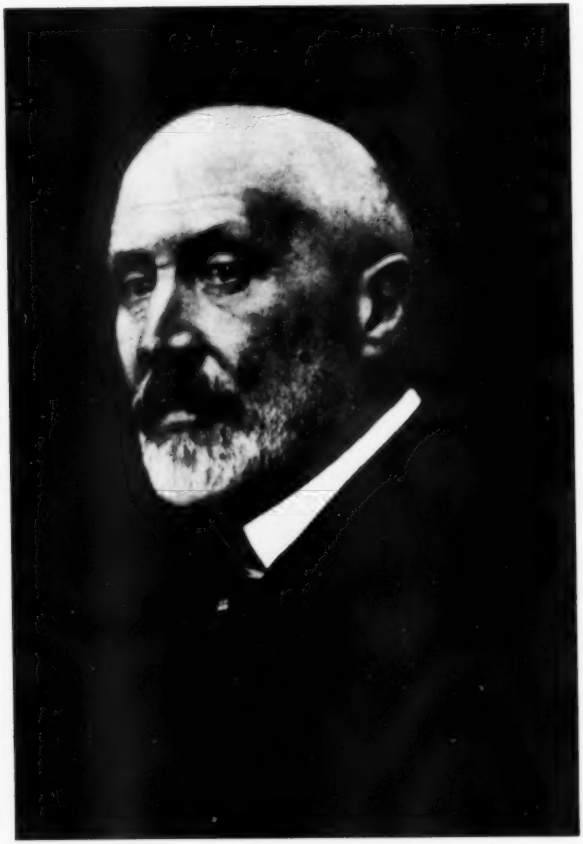


Baron Roland von Eötvös, born in Budapest July 27, 1848, died April 8, 1919. His genius enriched the realm of natural science with several notable contributions; he was responsible not only for the theory underlying the torsion balance but was also himself entirely responsible for the development of fibres and, with the aid of the mechanic F. Süss, for the building of instruments capable of measuring the tiny gravitational effects—an achievement that represented almost a lifetime of patient experimentation unselfishly devoted to pure science. More than thirty years ago he carried out extensive field surveys with his own instruments and directed attention to the importance of the instrument in geology.

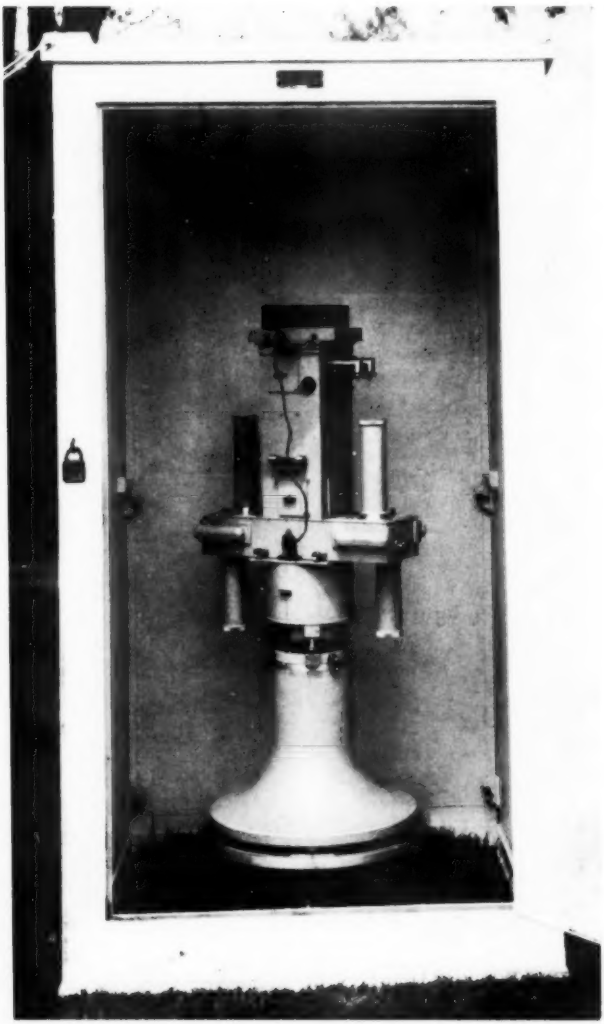
Journal of the Royal Astronomical Society of Canada, 1934

PLATE II

THE SÜSS EÖTVÖS TORSION BALANCE

This instrument is designed for visual observation.

PLATE III



THE ASKANIA EÖTVÖS TORSION BALANCE, SCHWEYDAR Z MODEL

This is a photographically recording instrument.

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THE THEORY AND OPERATION OF THE EÖTVÖS TORSION BALANCE

By A. H. MILLER

(With plates I, II, III)

INTRODUCTION

THE above title formed the subject of one of a series of lectures given before members of the Society at the Dominion Observatory during the early part of this year. The purpose of this lecture was to familiarize a certain number of interested members with the underlying theory of the instrument, with the quantities it measures and the manner in which the measurements are made.

In so far as the Eötvös torsion balance as a geophysical prospecting instrument is concerned it measures two important quantities: first the force arising from the differential curvature of the level surface, which was called by Eötvös the horizontal direction force and has been abbreviated by English writers to H.D.T. (Horizontal Directing Tendency), and secondly the gradient of gravity, which is in turn due to the curvature of the vertical. The level surface at any place is the surface of a liquid such as water when placed in a container and allowed to come to rest. Although we know very well that the average level (sea) surface of the earth is a curved surface (being nearly a spheroid) the conception that the surface of the water in a small container is a plane or flat surface has become very fixed in our minds and with it the idea that the vertical which at any point is the perpendicular to the level surface is a straight line. We regard the vertical over the surface as being represented by an infinite series of straight

lines all parallel to one another. When we come to the small quantities that the torsion balance measures this is only an approximation. Actually the level surface at any point is usually a curved surface with its curvature varying in different directions, and the vertical over the surface is represented by a series of lines inclined to one another. Moreover the direction of any one of these lines is continually changing as we follow it along its length. Even the spheroid represents only on the average the level surface of the earth. Owing to the uneven distribution of material in the crust of the earth there are innumerable small bumps and hollows in this average figure or surface. It is with these that we are concerned with the torsion balance.

Curvature of the Level Surface—the Horizontal Directing Forces.—Fig. 1 represents the essential parts of an Eötvös torsion balance, a light beam suspended by a torsion fibre, weighted at one end and balanced by an equal weight suspended from its other end. As we suppose the curvature of the level surface to remain the same over the region occupied by the instrument (*i.e.*, the same at the upper and lower weights) it will be seen that the rotational couple due to the differential curvature is the same if we suppose the lower hanging weight to be placed on the end of the beam immediately above the actual position shown in the diagram. For the purpose then of considering the effect of the curvature forces we may simplify matters somewhat by supposing the Eötvös balance to be replaced by a suspended beam weighted at each end.

FIG. 1. Diagram of Eötvös Torsion Balance.

Fig. 2 is a photograph of a model illustrating the curvature effect in the case of a cylindrical level surface. The central rod may be taken to represent a torsionless fibre. The pencils represent the directions of the vertical (always perpendicular to the surface of the cylinder) at the two weights. It can be seen there are components of gravity acting on both weights tending to turn the beam into a direction parallel to the axis of the cylinder or along the direction of least curvature.

In Fig. 3 are reproduced some diagrams of more than ordinary

interest published by Eötvös to illustrate the effect of curvature. In these drawings the tangent plane is the horizontal plane at any point which we might suppose to be at the centre of our beam or the centre of gravity of the torsion balance. If we take the four diagrams representing the force components in the tangent planes and imagine further that our beam is supsended so that it lies

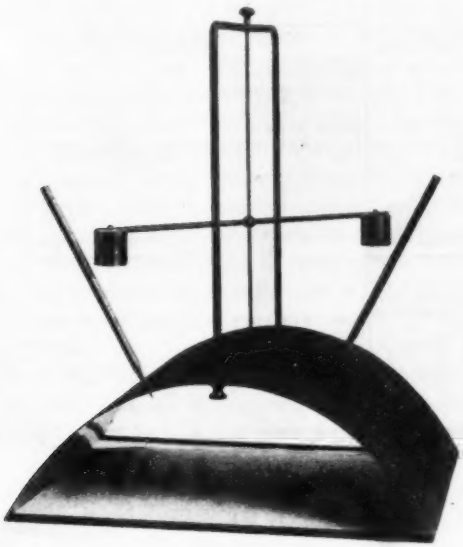

FIG. 2.—Model illustrating curvature couple in the case of a cylindrical equipotential surface.

symmetrically within diagonally opposite quadrants it can be seen that in the case of the general convex surface and the cylinder the beam for stable equilibrium will be forced towards the direction of least curvature and that for the sphere the beam is in equilibrium in any azimuth. The circular diagram shows this rotational effect more clearly by resolving the force vectors in the directions in

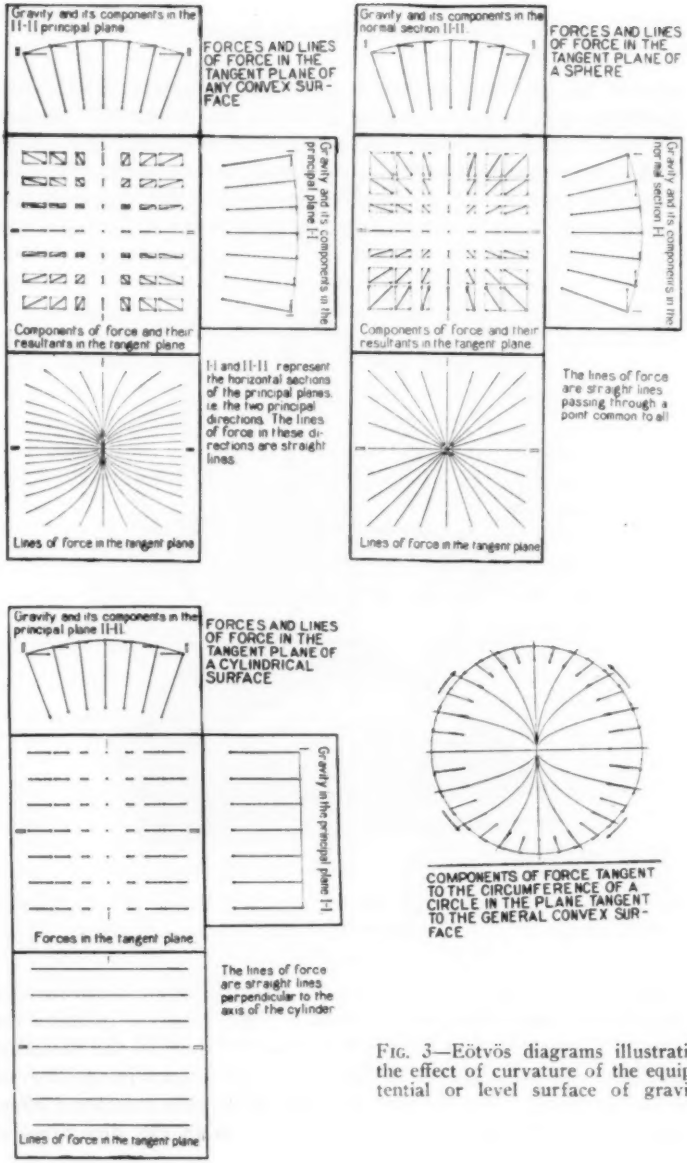
Gravity and its components in the II-II principal plane
FORCES AND LINES OF FORCE IN THE TANGENT PLANE OF ANY CONVEX SURFACE
Gravity and its components in the principal plane I-I
Components of force and their resultants in the tangent plane
I-I and II-II represent the horizontal sections of the principal planes, i.e. the two principal directions. The lines of force in these directions are straight lines.
Lines of force in the tangent plane
Gravity and its components in the normal section II-II
FORCES AND LINES OF FORCE IN THE TANGENT PLANE OF A SPHERE
Gravity and its components in the normal section I-I
Components of force and their resultants in the tangent plane
The lines of force are straight lines passing through a point common to all
Lines of force in the tangent plane
Gravity and its components in the principal plane II-II
FORCES AND LINES OF FORCE IN THE TANGENT PLANE OF A CYLINDRICAL SURFACE
Gravity in the principal plane I-I
Forces in the tangent plane
The lines of force are straight lines perpendicular to the axis of the cylinder
Lines of force in the tangent plane
COMPONENTS OF FORCE TANGENT TO THE CIRCUMFERENCE OF A CIRCLE IN THE PLANE TANGENT TO THE GENERAL CONVEX SURFACE

FIG. 3—Eötvös diagrams illustrating the effect of curvature of the equipotential or level surface of gravity.

which they are effective in producing rotation, *i.e.*, tangent to the circumference. In the case of the sphere the force is everywhere entirely normal to the circumference and consequently there is no tendency to produce rotation.

If only the direction in which the beam tends to set itself is desired it is not necessary to analyse the directions of the forces as has been done above. The tendency for all material things, when free to move, is to fall to the lowest level. Water accomplishes this by running down hill. The beam and its weight in a sense fall to the lowest level when they reach the position in which they are nearest the level surface. For a convex surface this is plainly along the direction of least curvature (East and West in the case of the earth) and for a concave surface it is along the direction of greatest actual curvature but still in the direction of least algebraic curvature if we regard the curvature of a convex surface as positive. The semicylindrical surfaces corresponding respectively to the anticline and syncline in geology may be used to illustrate this principle. A more extreme case is that of the saddle back, in which case the position of equilibrium is obviously along the direction from pommel to cantle.

Curvature of the Vertical—the Gradient.—The gradient of gravity is the rate at which gravity is changing in the horizontal plane and in that particular direction in this plane in which its rate of change is greatest. Let us suppose at the point we have under consideration this is to the north, as is normally the case in the northern hemisphere. From a consideration of the principle of the conservation of energy it can easily be shown that in this case the vertical must be a curved line concave on the north side. Suppose the plane of the paper in Fig. 1 to be East-West and the direction of gravity at the upper weight to be also in this plane. At the lower weight it will be inclined to this plane and consequently there is a component of gravity acting on the lower weight in the direction of north tending to turn the beam in the counter-clockwise direction. If the difference in height between the weights were exactly one centimetre the component would be exactly equal to the gradient of gravity. In order to obtain a greater component and consequently larger turning effect the distance amounts to several

centimetres in the actual instrument. Similarly it can be seen that the turning moment due to the curvature can be increased by making the length of the beam greater. Increasing the mass of the weights also increases the rotational couples in both cases.

When the torsion balance is set in any direction it comes to equilibrium in a position in which the torsion in the fibre is balanced by the effect of the two gravitational couples. By observing the amount of torsion produced in the fibre supporting the suspended system when placed in several azimuths and knowing the various constants of the system (dimensions and mass of weights and beams, torsion constant of fibre, etc.) it is possible to determine the values of the differential curvature and the gradient. For a single beam as indicated in figure 1 five azimuths equally spaced are required. All instruments nowadays are built with two beams placed side by side and end for end as in this case observations in only three azimuths are necessary, thus reducing the time of observation to nearly one half—a very important consideration as it takes from 40 to 60 minutes for the beams to come to rest for observation in any azimuth. The suspended systems are placed in a triple housing of aluminium and in order to guard against rapid temperature changes during observation the instrument is set up in some sort of portable hut.

Theory of the Torsion Balance and the Quantities it Measures

Gravitational Potential.—While it is true that the fundamental relations in connection with the torsion balance may be established without resorting to the calculus (one of the most interesting of such proofs is that by Eötvös himself) it is also true that the torsion balance affords a most interesting and instructive application of partial differentiation and the elementary theory of gravitational potential. For this reason, and because the results are obtained in a somewhat more direct manner by so doing, use is made of the calculus in what follows. We begin therefore with the statement that the partial derivative of the gravitational potential function U is equal to the gravitational force X in the direction of x, X being

taken as positive in the direction of increase of U, *i.e.*, $\frac{\partial U}{\partial x} = X$. It may be remarked in passing that U includes not only the potential due to the attraction of matter in the earth but also in addition a part which is due to its rotation. The force X is represented by the projection of gravity in the direction of x as indicated in Eötvös' diagrams (Fig. 3). If at any point we select as origin the values of the forces in the directions of the three coordinate axes are X_0, Y_0, Z_0, their values at any point x, y, z (which is sufficiently close to the origin so that the derivatives of X, Y, Z are constant, *i.e.*, so that their second derivatives or the third derivatives of U vanish) are

$$\left.\begin{aligned} X &= X_0 + x\frac{\partial X}{\partial x} + y\frac{\partial X}{\partial y} + z\frac{\partial X}{\partial z} \\ Y &= Y_0 + x\frac{\partial Y}{\partial x} + y\frac{\partial Y}{\partial y} + z\frac{\partial Y}{\partial z} \\ Z &= Z_0 + x\frac{\partial Z}{\partial x} + y\frac{\partial Z}{\partial y} + z\frac{\partial Z}{\partial z} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Let O (Fig. 4) be the origin and B the point o, o, z, and let the arc OA represent the direction of the vertical between the points O and A. Suppose the gradient of gravity to be in the direction of x, and hence equal to $\frac{\partial X}{\partial z}$ or $\frac{\partial_2 U}{\partial x \partial z}$, at B, $X = X_0 + \frac{\partial X}{\partial z} \cdot z$ which may also be regarded as the value of X at A since BA the distance the vertical bends away from the straight line OB is very small compared with the length OB. If we take OB to be tangent to the vertical at O then $X_0 = o$ and $\therefore X = \frac{\partial X}{\partial z} \cdot z = \text{gradient} \times z = g \sin \epsilon = g\epsilon$ since ϵ is small. If z is taken equal to unity then X the projection of gravity on the horizontal plane 1 cm. distant = gradient = also $\frac{g}{R}$ or gravity divided by the radius of curvature of the vertical.

In order to get some conception of the magnitude of the gradient of gravity and of what the curvature of the vertical amounts to let us consider the case where z is not unity but equal to some height h say and let α equal the small angle through which the vertical turns in this height, then gradient $\times h = X = g\alpha$. In this

latitude the normal gradient due to the spheroid is equal to about 8×10^{-9} c.g.s. units and $g=981$ cm. per sec. per sec. If these values and that for 1 second of arc $=5\times10^{-6}$ are substituted in the last equation it will be found that in this latitude the vertical normally bends through one second of arc in a height of about six kilometres or three and one half miles, an angle equivalent to that subtended by the large Canadian cent at approximately the same distance. The instrument is capable of measuring a gradient of 1×10^{-9} c.g.s. unit. A very large gradient is represented by 100×10^{-9} c.g.s. unit.

Let $APBC$ (Fig. 5) represent a vertical section of an equipoten-

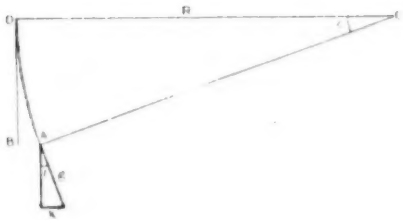

FIG. 4

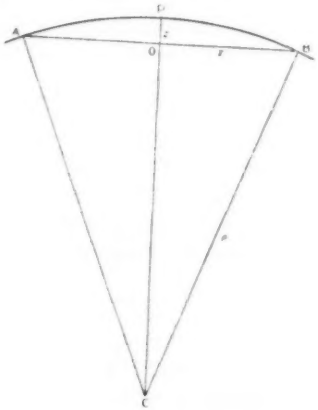

FIG. 5

tial surface passing through the points APB. Let O be the origin and OB and OP represent the directions of the axes of x and z respectively. The difference of potential between O and B (ΔU_{OB}) will by definition be equal to the difference of potential (ΔU_{OP}) between O and P. The force in the direction of x at O is X_0. At B it is $X_0+x\dfrac{\partial X}{\partial x}$ if B is not far removed from O.

$$\therefore \Delta U_{OB}=xX_0+\frac{x^2}{2}\ \frac{\partial X}{\partial x} \text{ and similarly}$$

$\Delta U_{OP}=zZ_0+\frac{z^2}{2}\frac{\partial Z}{\partial z}$. Let us suppose further that OP represents the direction of the vertical at O, and hence $X_0=0$.

Then we have equating ΔU_{OB} and ΔU_{OP}

$\frac{x^2}{2}\frac{\partial X}{\partial x}=z\left(Z_0+\frac{z}{2}\frac{\partial Z}{\partial z}\right)=-z\times$value of gravity at a point midway between O and $P=-z\times g$ or $\frac{\partial_2 U}{\partial x^2}=-\frac{g}{\rho}$ where ρ is the radius of curvature of the surface in the xz plane since $2\rho.z=x^2$ approximately.

As will be seen later on the H.D.T. is defined as being equal to $g\left(\frac{1}{\rho_1}-\frac{1}{\rho_2}\right)$ where $\frac{1}{\rho_1}$ and $\frac{1}{\rho_2}$ are the curvatures in the two principal planes *i.e.*, of maximum and minimum curvature.

In text books on curvature of surfaces (*e.g.*, Smith's Solid Geometry) it is shown that $\frac{1}{\rho_\theta}=\frac{\cos^2\theta}{\rho_2}+\frac{\sin^2\theta}{\rho_1}$ where $\frac{1}{\rho_\theta}$ is the curvature in the direction making an angle θ with the principal plane in which the curvature is $\frac{1}{\rho_2}$, which we shall suppose to be the minimum curvature. If we choose $\frac{1}{\rho_\theta}$ to be the curvature in the direction of x (that is θ is the angle between the x axis and the direction of least curvature) then

$$\frac{1}{\rho_x}=\frac{\cos^2\theta}{\rho_2}+\frac{\sin^2\theta}{\rho_1}$$

$$\frac{1}{\rho_{\theta+\frac{\pi}{2}}}=\frac{1}{\rho_y}=\frac{\sin^2\theta}{\rho_2}+\frac{\cos^2\theta}{\rho_1}$$

$$\frac{1}{\rho_x}-\frac{1}{\rho_y}=\frac{\cos^2\theta-\sin^2\theta}{\rho_2}-\frac{\cos^2\theta-\sin^2\theta}{\rho_1}$$

$$=-\left(\frac{1}{\rho_1}-\frac{1}{\rho_2}\right).\cos 2\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{or } \frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{dx^2} = -g\left(\frac{1}{\rho_1} - \frac{1}{\rho_2}\right).\cos 2\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$= -R.\cos 2\theta$$

where R represents the H.D.T. and is essentially a positive quantity.

The Gravitational Couple Acting on a Beam Suspended by a Fibre Attached at a Point Above its Centre of Gravity.—Let us choose the z axis to be parallel to the vertical at O (Fig. 6), which is taken as origin. This will not necessarily coincide precisely with the fibre as owing to possible variation in the Z forces acting on the beam and the resulting tilting a slight lateral displacement of the fibre may be produced which will give rise to a tensional couple to balance the tilting.

The turning moment in the clockwise direction about the z axis

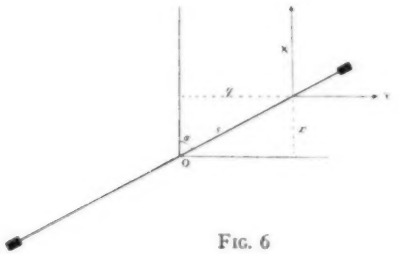

FIG. 6

due to the forces acting on an element of mass dm is $(-Xy+Yx)dm$. If we substitute in this equation the values of X and Y from equations (1) we have X_0 and Y_0 coming into the expression for the turning moment. For the assumed direction of z, X_0 and Y_0 are zero. But even if z were not in the direction of gravity the effect of X_0 and Y_0 when summed up over the whole beam would not tend to produce rotation if the beam is loaded symmetrically. The turning moment therefore neglecting these quantities

$$= dm\left(-xy\frac{\partial X}{\partial x} - y^2\frac{\partial X}{\partial y} + x^2\frac{\partial Y}{\partial x} + xy\frac{\partial Y}{\partial y}\right)$$

or, since $x = r\cos\alpha$ and $y = r\sin\alpha$,

$$= r^2 dm\left[\frac{\partial_2 U}{\partial x \partial y}\cos 2\alpha + \left(\frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{\partial x^2}\right)\frac{\sin 2\alpha}{2}\right]$$

which if summed up for the entire beam

$$=K\left[\frac{\partial_2 U}{\partial x \partial y} \cdot \cos 2\alpha + \left(\frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{\partial x^2}\right)\frac{\sin 2\alpha}{2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where K is the moment of inertia of the beam as the cross section of the beam is small compared with its length. This limitation applies also to the second expression preceding (4) when the element of mass is not in the plane $z=0$. This couple (4) is due to the curvature of the level surface.

Gravitational Couple Acting on the Torsion Balance.—For this purpose we suppose the weight on the right in figure 6 lowered by means of a *light* wire to a distance h beneath the beam. Again we do not require the moments due to Z. We do require the changes in moment due to the fact that the forces acting on the lower weight have values differing from the previous ones by the amounts $\frac{\partial X}{\partial z} \cdot h$ and $\frac{\partial Y}{\partial z} \cdot h$ respectively which produce at the centre moments of

$$-\frac{\partial X}{\partial z} \cdot yhm \text{ and } \frac{\partial Y}{\partial z} \cdot xhm \text{ respectively}$$

$$= -\frac{\partial X}{\partial z} mhl \sin \alpha + \frac{\partial Y}{\partial z} mhl \cos \alpha \text{ where}$$

m is the mass of the lower hanging weight and l its torsion arm.

So then the complete effect of the gravitational couple in the case of the torsion balance is

$$K\frac{\partial_2 U}{\partial x \partial y}\cos 2\alpha + K\left(\frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{\partial x^2}\right)\frac{\sin 2\alpha}{2} + mhl\frac{\partial_2 U}{\partial y \partial z}\cos \alpha$$

$$-mhl\frac{\partial_2 U}{\partial x \partial z}\sin \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This is the moment about the z axis. The turning moment about the fibre will be the above expression multiplied by the cosine of the angle between the vertical and the fibre, so that the difference is practically infinitesimal. Compared with the first position the lowering of the weight is bound to produce a slight tilting of the beam owing to the variation of gravity with height. For a

more rigorous proof the reader is referred to the original paper of Eötvös.

Horizontal Directing Tendency.—Representing by F the clockwise couple in equation (4) we have

$$F = K\left(\frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{\partial x^2}\right)\frac{\sin 2\alpha}{2} + K\frac{\partial_2 U}{\partial x \partial y}\cos 2\alpha \quad \ldots\ldots (6)$$

$$= 0 \text{ when } \tan 2\alpha = \frac{-2\dfrac{\partial_2 U}{\partial x \partial y}}{\left(\dfrac{\partial_2 U}{\partial y^2} - \dfrac{\partial_2 U}{\partial x^2}\right)}$$

When F is equal to zero the beam is in one of the principal planes of curvature. It is well known that these are at right angles to one another, a fact that is borne out by equation (2) which shows that the curvature difference in the coordinate planes is equal to the maximum curvature difference for $\theta = 0$ and multiples of $\frac{\pi}{2}$. Let us for the moment choose our axes of x' and y' to lie in these planes. The angle α is now measured from one of these planes and the derivatives are now their values in the principal planes. When the beam is in one of these planes, *i.e.*, for $\alpha = 0$ or $\frac{\pi}{2}$, F is zero, and the first member on the right hand side of equation (6) vanishes, which shows that $\frac{\partial_2 U}{\partial x \partial y}$ must be zero for either principal plane.

Let us suppose (Fig. 7) that the beam is moved by an angle u out of the principal plane. It follows that

$$F = \frac{K}{2}\left(\frac{\partial_2 U}{\partial y'^2} - \frac{\partial_2 U}{\partial x'^2}\right)\sin 2u$$

$$= -\frac{Kg}{2}\left(\frac{1}{\rho_{y'}} - \frac{1}{\rho_{x'}}\right)\sin 2u \quad \ldots\ldots (7)$$

As F is positive when clockwise and also u we see that the beam is in stable equilibrium for $g\left(\frac{1}{\rho_{y'}} - \frac{1}{\rho_{x'}}\right)$ positive because equation

(7) shows that for clockwise displacements of the beam for u less than $\frac{\pi}{2}$ the gravitational couple is counterclockwise and for values of u between $\frac{\pi}{2}$ and π the couple is clockwise and similarly for the third and fourth quadrants. The tendency is to bring the beam back into the x' direction provided $\frac{1}{\rho_{y'}} - \frac{1}{\rho_{x'}}$ is positive, *i.e.*, the beam tends to turn into the direction for which the curvature is algebraically least. In equation (7) it is apparent that the restoring couple irrespective of the dimensions of the beam or its angular

FIG. 7

displacement is always directly proportional to the quantity $g\left(\frac{1}{\rho_{x'}} - \frac{1}{\rho_{y'}}\right)$. It is somewhat comparable to the part played by g in the case of displacement in the vertical plane ($F = mgs \sin u$) and it was for this reason Eötvös called the expression $g\left(\frac{1}{\rho_{y'}} - \frac{1}{\rho_{x'}}\right)$ or $g\left(\frac{1}{\rho_1} - \frac{1}{\rho_2}\right)$ the horizontal direction force $= R$ say.

Returning again to the selection of the direction of x in any arbitrary direction (in a survey usually magnetic north) it is seen (equation 6) that the particular value of α, λ say, which gives no torsion in the fibre is given by

$$\frac{\sin 2\lambda}{\cos 2\lambda} = \frac{-2\dfrac{\partial_2 U}{\partial x \partial y}}{\dfrac{\partial_2 U}{\partial y^2} - \dfrac{\partial_2 U}{\partial x^2}} \qquad (8)$$

$$= \frac{-2\dfrac{\partial_2 U}{\partial x \partial y}}{g\left(\dfrac{1}{\rho_x} - \dfrac{1}{\rho_y}\right)} = \frac{2\dfrac{\partial_2 U}{\partial x \partial y}}{g\left(\dfrac{1}{\rho_1} - \dfrac{1}{\rho_2}\right)\cos 2\lambda} = \frac{2\dfrac{\partial_2 U}{dx \partial y}}{R \cos 2\lambda}$$

From which it follows that $2\dfrac{\partial_2 U}{\partial x \partial y} = R \sin 2\lambda$ ..... (9)

and as a result of this from (8)

$$\frac{\partial_2 U}{\partial y^2} - \frac{\partial_2 U}{\partial x^2} = -R \cos 2\lambda \qquad (10)$$

and $\therefore R = \text{H.D.T.} = \sqrt{\left(\dfrac{\partial_2 U}{\partial y^2} - \dfrac{\partial_2 U}{\partial x^2}\right)^2 + \left(2\dfrac{\partial_2 U}{\partial x \partial y}\right)^2}$

and the direction of R is given by

$$\tan 2\lambda = \frac{-2\dfrac{\partial_2 U}{\partial x \partial y}}{\left(\dfrac{\partial_2 U}{\partial y^2} - \dfrac{\partial_2 U}{\partial x^2}\right)} \qquad (11)$$

Although equation (11) would on the surface apparently give the angle λ without any trouble confusion arises as λ having a range from 0° to 180°, 2λ may lie in either one of two quadrants thus introducing an uncertainty of 90° in the direction of R. If the algebraic signs of the trigonometric functions sine, cosine and tangent are considered and the convention adopted in equations 9 and 10 that R is to be taken as positive that is that λ is to be measured from the direction of least curvature (compare equation 7 and what follows) then it will be found that the following table will give the direction of R.

Sign of U_Δ	Sign of $2U_{xy}$	Quadrant of 2λ
+	+	2λ in 2nd quadrant
+	−	2λ in 3rd "
−	+	2λ in 1st "
−	−	2λ in 4th "

The signs of U_Δ and U_{xy} are obtained from the observations where the instrument is set up. A much handier table for general use was given to the writer by Dr. James Phemister of the Geological Survey of Scotland and is as follows:

Sign of U_Δ	Sign of $2U_{xy}$	Sign of θ	Direction of R or Least Curvature
+	+	−	$90°+\theta$
+	−	+	$90°+\theta$
−	+	+	θ
−	−	−	θ

For the purpose of this table 2θ is taken to be that angle less than 90° whose tangent is numerically equal to the ratio $\frac{2U_{xy}}{U_\Delta}$. The sign of θ is given in the third column. The positive direction of θ is to the East of North, so that the azimuths of R are in the four cases (1) $<90°$ East of North, (2) $>90°$ East of North, (3) $\theta°$ East of North, (4) $\theta°$ West of North.

Gradient of Gravity.—The gradient being the maximum rate of change of g in the horizontal

$$= \sqrt{\left(\frac{\partial_2 U}{\partial x \partial z}\right)^2 + \left(\frac{\partial_2 U}{\partial y \partial z}\right)^2}$$

and its direction is given by $\tan \alpha = \dfrac{\dfrac{\partial_2 U}{\partial y \partial z}}{\dfrac{\partial_2 U}{\partial x \partial z}}$

The Measurement of the Gravitational Effects with the Torsion Balance

Single Beam Instrument.—The turning moment of the gravitational forces represented by equation (5) is balanced in the instrument by the torsion produced in the fibre. If τ is the torsion constant of the fibre (the restoring couple per unit angle of twist)

and θ the angle through which the fibre has been twisted when equilibrium has been attained between the two couples then

$$\tau\theta = KU_{xy} \cos 2\alpha + KU_{\triangle} \frac{\sin 2\alpha}{2} + mhlU_{yz} \cos \alpha - mhlU_{xz} \sin \alpha \quad . . (12)$$

where the abbreviations for the differentials are obvious on comparison with equation (5). Regarding $U_{\triangle}$ as a single quantity there are 4 unknown derivatives in this equation as well as θ. It is therefore necessary to observe with the instrument set in five different azimuths (α) to determine all the unknown quantities. The constants τ, K, m, h, and l are of course measured once for all. With a single beam the instrument is set up successively in five azimuths 0°, 72°, 144°, 216°, 288° and the angles ϕ_1, ϕ_2, ϕ_3, ϕ_4, ϕ_5 defining the position of the beam in each case are determined. These may be measured from any reference plane moving with the instrument (*e.g.*, the side of the beam box). The deflection from the position of no torsion in any azimuth is $\phi_0 - \phi_n$ where ϕ_0 is the reading corresponding to no torsion in the fibre. If the five equations for the values of α specified are written out it will be found that the members of the right hand side add up to zero showing that the unknown angle $\phi_0 = \frac{\phi_1+\phi_2+\phi_3+\phi_4+\phi_5}{5}$.

The five equations for θ may now be written out substituting for it in turn $\phi_0 - \phi_1$, $\phi_0 - \phi_2$ etc. and for α,0°, 72° etc. from which the values of the derivatives may be obtained. In practise the equations are solved for the derivatives expressing them in terms not of the angular differences ϕ as indicated but in scale division differences. The theoretical expression for each derivative is obtained from the azimuth equations. The values of the derivatives at any place where the instrument is set up are obtained very simply and readily by substituting the observed scale division readings in the theoretical expressions. In the case of a visual instrument these are obtained from a scale and mirror attached respectively to the beam box and beam of the instrument. In the case of a photographically recording instrument they are obtained by scaling the beam positions as recorded on a photographic plate.

Double Beam Instrument.—As already explained considerable time is saved with the double beam instrument. There is also

the advantage that the instrument is not exposed to the additional period of possible temperature fluctuation. The fundamental equation is again equation (12). If we express it in terms of the scale division readings it takes the form

$$n_0 - n = a U_\triangle \sin 2\alpha + 2a U_{xy} \cos 2\alpha - b U_{xz} \sin \alpha + b U_{yz} \cos \alpha$$

where $a = D \frac{K}{\tau}$ and $b = 2D \frac{mhl}{\tau}$

D is the distance from scale to mirror in scale divisions. The instrument is set successively in azimuths for No. 1 beam of 0°, 120° and 240°. For the same settings the azimuths of the second beam are of course these values with the addition of 180 degrees in each case. If we substitute in succession the readings n for each beam and the corresponding values of α in the fundamental equation we obtain 6 equations from which may be obtained the reading corresponding to no torsion in each beam (in this case the mean of the three readings) and the values of the four derivatives.

If this substitution is made it will be found that

$$U_{xz} = -\frac{a'}{\sqrt{3}(ab'+a'b)}\left[\{n_0-n_2) - (n_0-n_3) - \frac{a}{a'}\{(n'_0-n'_2)-(n'_0-n'_3)\}\right]$$

$$U_{yz} = \frac{a'}{ab'+a'b}\left[(n_0-n_1) - \frac{a}{a'}(n'_0-n'_1)\right]$$

$$U_\triangle = -\frac{b'}{\sqrt{3}(ab'+a'b)}\left[\{n_0-n_2)-(n_0-n_3)\} + \frac{b}{b'}\{(n'_0-n'_2)-(n'_0-n'_3)\}\right]$$

$$2U_{xy} = \frac{b'}{(ab'+a'b)}\left[(n_0-n_1) + \frac{b}{b'}(n'_0-n'_1)\right]$$

where the unprimed letters refer to the first beam and the primed to the second beam.

$$(n_0-n_1)+(n_0-n_2)+(n_0-n_3)=0 \text{ or } n_0=\frac{n_1+n_2+n_3}{3}$$

$$(n'_0-n'_1)+(n'_0-n'_2)+(n'_0-n'_3)=0 \text{ or } n'_0=\frac{n'_1+n'_2+n'_3}{3}$$

from which it follows that

$$(n_0-n_2)-(n_0-n_3)=2(n_0-n_2)+(n_0-n_1)$$
$$=-[2(n_0-n_3)+(n_0-n_1)]$$
$$(n_0-n_2)+(n_0-n_3)=-(n_0-n_1)$$

with similar expressions for the other beam. These last equations serve as a check on the observations and may be substituted in the above equations for the derivatives.

The required constants of the Süss balance belonging to the observatory are as follows

Beam I		Beam II	
D	$=44.89$ cms.	D'	$=44.89$ cms.
	$=1346.7$ scale divisions		$=1346.7$ scale divisions
K	$=1761$ c.g.s.	K'	$=1754$ c.g.s.
τ	$=0.03972$ c.g.s.	τ'	$=0.03978$ c.g.s.
m	$=8.5$ gms.	m'	$=8.5$ gms.
h	$=31.85$ cms.	h'	$=31.87$ cms.
l	$=9.99$ cms.	l'	$=9.98$ cms.

If these are used to determine a, a' and b and b' it will be found on substitution in equations (13) that the derivatives for the observatory instrument can be obtained from the following

$$U_{xz} = 1.5712\,[(n_2-n_0)-(n_3-n_0)-(1+0.00551)\,\{(n'_2-n'_0)-(n'_3-n'_0)\}]\times 10^{-9} \text{ c.g.s.}$$

$$U_{yz} = 2.7214\,[(n_2-n_0)+(n_3-n_0)-(1+0.00551)\,\{(n'_2-n'_0)+(n_3-n'_0)\}]\times 10^{-9} \text{ c.g.s.}$$

$$U_{\triangle} = 4.8436\,[(n_2-n_0)-(n_3-n_0)+(1+0.00188)\,\{((n'_2-n'_0)-(n'_3-n'_0)\}]\times 10^{-9} \text{ c.g.s.}$$

$$2U_{xy} = 8.3894\,[(n_2-n_0)+(n_3-n_0)+(1+0.00188)\,\{(n'_2-n'_0)+(n'_3-n'_0)\}]\times 10^{-9} \text{ c.g.s.}$$

The unit 10^{-9} c.g.s. in which the results are expressed is commonly termed the Eötvös unit and designated by the letter E. In observing with the instrument the lower hanging weight of beam I should in the initial azimuth ($\alpha=0$) be set on the north side of the instrument. The scales are graduated so that a clockwise deflection is represented by a decrease in the reading n. It will be seen that this agrees in so far as sign is concerned with the requirements of the fundamental equations.

Observations in the Field.—In the accompanying field notes for a station (A_4) in the vicinity of Ottawa d_1 stands for (n_1-n_0), d_2 for (n_2-n_0) and d_3 for (n_3-n_0) and similar expressions for beam 2. Three values are taken for d_2+d_3 the extra result being the value for $-d_1$. Owing to the way in which the means (n_0) have

STATION A_4, LEITRIM, ONT. INSTRUMENT - SUSS.
SEPT. 29, 1930. OBSERVER - A.H.MILLER.

AZIMUTH	TIME	TEMP	BEAM I n	n_0	$n-n_0$	BEAM II n'	n'_0	$n'-n'_0$
N	3.55 P.M.	14.0 C	157.0			441.2		
120	4.55 "	13.7	151.3	155.9	-4.6	453.1	445.3	+7.8
240	6.15 "	12.7	159.3	155.8	+3.5	441.5	445.1	-3.6
N	7.15 "	12.2	156.7	155.7	+1.0	440.6	445.0	-4.4
120	8.15 "	11.5	151.1	155.6	-4.5	452.9	444.8	+8.1
240	9.15 "	11.0	159.0	155.4	+3.6	440.9	444.6	-3.7
N	10.15 "	10.7	156.2			440.0		

	d_2-d_3	d_2+d_3	$d'_2-d'_3$	$d'_2+d'_3$
	-8.1	-1.1	+11.4	+4.2
	-8.1	-1.0	+11.8	+4.4
		-0.9		+4.4
MEAN	-8.1	-1.0	+11.6	+4.3

	U_{xz}	U_{yz}	U_z	$2U_{xy}$
	$=1.57(-8.1-11.6-0.1)$	$=2.72(-1.0-4.3)$	$=4.84(-8.1+11.6)$	$=8.39(-1.0+4.3)$
	$=1.57(-19.8)$	$=2.72(-5.3)$	$=4.84(+3.5)$	$=8.39(+3.3)$
OBSERVED	-31.1	-14.4	+16.9	+27.7
NORMAL	+ 7.9	+ 2.0	+ 4.5	- 2.4
TERRAIN	- 3.1	- 5.0	+15.0	+ 7.8
TOPOGRAPHIC	0	.0	- 3.4	- 2.4
SUBTERRANEAN EFFECT IN EOTVOS UNITS	-35.9	-11.4	+0.8	+24.7

GRADIENT = 37.7 E. AT 17° 37' WEST OF SOUTH H.D.T = 24.7 E. AT 45° 56' EAST OF NORTH

Field Notes, Station A4, Leitrim, Ont.

been formed there is no use when this method is followed of using the two alternative values $2d_2+d_1$ and $-(2d_3+d_1)$ for d_2-d_3 as d_2-d_3 itself represents the average of the three.

In order to maintain a check on the behaviour of the instrument it is desirable to repeat the observations in at least some of the azimuths as indicated in the field notes. How many repetitions

should be made is gathered from experience with the instrument and depends for the most part upon the temperature gradients to which the instrument is subjected during the observations. For the station at Leitrim it is apparent that much the same result would have been obtained if the readings in the last three azimuths had been omitted.

The observed values must be corrected for the effect of the irregularities in the ground surface (terrain) and for the normal effects due to the earth. In the accompanying field notes the terrain correction is the correction for the area included within the circumference of a circle of 50 metres described about the station as centre. The topographic correction here represents the correction for the area between 50 and 400 metres. It was not necessary to carry the correction to the gradient farther than the 50 metres as beyond that it was negligible. Sometimes it is necessary to carry the correction for curvature beyond 400 metres from the station. The normal corrections for latitudes from 40° to 60° were computed by Eötvös from Helmert's gravity formula and Bessel's ellipsoid. The terrain effects are determined from levels along radial lines (usually 8) from the station or from a combination of levels and contour maps.

For determining the effect use has been made by the writer of Jung's modification of Schweydar's formulae and also of Schweydar's original formulae. Forms are printed for computing. For the computations a small high speed calculator is used. This can be operated either by an electric current (attaching to light circuit) or by hand and in either case simplifies to a great extent the work of computation.

Depending on which terrain formula is used the instrument is set with its centre of gravity either at 90 cms. or 1 metre above the ground.

Determination of the Instrumental Constants.—When one purchases an instrument at the present time he is in the fortunate position that the constants are supplied by the makers. Nevertheless a few remarks about their determination is of interest and in this respect we are concerned only with the moment of inertia (K) of the suspended system and the torsion constant (τ) of the

fibre as the determination of the other constants consists merely of quite simple measurements. The value of τ may be obtained in either of two ways (1) by bringing a lead sphere within a short distance of the lower hanging weight and observing the deflection produced on the balance (2) by taking the fibre out of the instrument and suspending from it a mass (*e.g.*, a small cylinder) and observing the time of torsional vibration.

Similarly K may be determined in two ways: (1) as was done by Eötvös, having obtained τ by the method (1) above he observed the time of vibration of the balance in the instrument and from the relation time of vibration $\tau = \pi \sqrt{\frac{K}{\tau}}$ obtained K; (2) by comparing the time of vibration of the suspension and a cylinder of known moment of inertia when each is suspended from the same fibre, which need not be the fibre of the instrument.

The relation $\tau = \pi \sqrt{\frac{K}{\tau}}$ is obtained when in the equation of motion of the beam the gravitational restoring couple is neglected. This will vary according to the azimuth. In order to correct for the effect it is necessary to observe the time of vibration in more than one azimuth. For the beam weighted at each end it was shown by Eötvös that observations in two azimuths at right angles are sufficient. The formula connecting the constants is $\frac{K}{\tau} = \frac{1}{2\pi^2}\left[T_1^2 + T_2^2\right]$ where T is the half period. In the case of the torsion balance observations in 4 azimuths normal to one another are required. That the effect is not negligible in some cases is shown by the fact that in one of Eötvös' original balances the difference between the semi-periods in the two azimuths amounted to 3 seconds.

Dominion Observatory, Ottawa,
November, 1932.

BIBLIOGRAPHY

The following is a list of publications dealing as a rule more particularly with the torsion balance and the theory in connection with it rather than with surveys and the application of the instrument. In certain cases, as indicated, abstracts of the papers are to be found in either Science Abstracts (Section A) or in the Annotated Bibliography of Economic Geology. The letter O following the title of the paper is an indication that the publication is in the Library of the Dominion Observatory. The letter G refers similarly to the Library of the Geological Survey.

Roland von Eötvös. Vizsgálatok a gravitatio és mágnesség köráböl; Mathematikai és Természettudományi Értésitö, XIV Kötet, 1896.

Untersuchungen über Gravitation und Erdmagnetismus. Wiedemann's Annalen der Physik und Chemie, Neue Folge, Band 59, pp. 354-400, 1896.—O.

Étude sur les surfaces de niveau et la variation de la pesanteur et de la force magnétique. Rapports présentés au congrès international de physique réuni à Paris en 1900, pp. 371-393, Tome III.

Bestimmung der Gradienten der Schwerkraft und ihrer Niveauflächen mit Hilfe der Drehwage: Verhandlungen der XV. allgemeinen Konferenz der internationalen Erdmessung in Budapest, (pp. 59), 1906.—O.

Programme des recherches gravimétriques dans les regions vésuviennes. Comptes rendus des seances de la première réunion de la commission permanente de l'Association Internationale de Sismologie réunie à Rome, 1906.

Roland von Eötvös. Bericht über Geodätissche Arbeiten in Ungarn besonders über Beobachtungen mit der Drehwage, XVI. allgemeine Konferenz der internationalen Erdmessung in London and Cambridge, (pp. 37), 1909.—O.

Die Niveauflächen und die Gradienten der Schwerkraft am Balatonsee, (pp. 64), 1908.—O.

Bericht über Arbeiten mit der Drehwage ausgeführt im Auftrage der Königl. Ungar. Regierung in den Jahren 1909-11. Verhandlungen der XVII. allgemeinen Konferenz der internationalen Erdmessung in Hamburg, 1912, Vol. 1, pp. 427-438.—O.

Roland von Eötvös, Desiderius Pekar, and Eugen Fekete. Beiträge zum Gesetze der Proportionalität von Trägheit und Gravität, Annalen der Physik, IV Folge, Bd. 68, pp. 11-66, 1922. Sc. Abs., Vol. 25, 2372.—O.

E. Fekete, Mikola, D. Pekar, and K. Tangl. Báró Eötvös Loránd Eléte és Andomángos müködése, Budapest, 1918.

D. Pekar. Báró Eötvös Loránd Geofizikai Mérései es Jelentöségük, pp. 29, 1917.—O.

Die geophysikalischen Messungen des Barons R. v. Eötvös. Die Naturwissenschaften, Jahrg. 7, pp. 149-159, 1919.

Baron Roland v. Eötvös wissenschaftliche Laufbahn. Die Naturwissenschaften, Jahrg. 7, Heft 22, pp. 387-391, 30 May, 1919.—O.

Báró Eötvös Loránd Emlékezete. Természettudományi Közlöny

735-738. Füzéteböl, Budapest, 1920. (Reprint contains photograph of Eötvös and probably appears also in volume referred to).—O.

Földalatti Vetödések Kimutatása A Torsiós Ingával. Mathematikai és Természettudományi Êrtesitö, XXXIX kötéteböl, 1921.—O.

D. Pekar. Die bei Feldmessung angewandete Drehwage von Baron Roland v. Eötvös. Zeitschrift für Instrumentenkunde, Jahrg. 42, pp. 173-178, 1922.—O.

Die Entwicklung, Empfindlickheit und verlässichkeit der Eötvösschen Original-Drehwagen. Zeitschrift für Instrumentenkunde, Jahrg. 45, pp. 486-493, 1925.—O.

Die Anwendbarkeit der Eötvösschen Drehwage im Felde. Zeitschrift für Instrumentenkunde, Jahrg. 43, pp. 187-195, 1923. Also Sc. Abs., Vol. 26, pp. 306-311, 1730.—O.

Die Entwicklung der Eötvösschen Originaldrehwagen. Die Naturwissenschaften, 16 Jahrg., Heft 51, pp. 1079-1088, 1928.—O.

M. Brillouin. Sur l'ellipticité du géoide dans le tunnel de Simplon; memoires présentés par divers savants à l'Académie des Sciences de l'Institut National, Vol. 33, No. 3, 1908. (Mention also in Comptes Rendus, Vol. CXLII, pp. 916-918, and Vol. CXLIII, pp. 405-407, 1906.—G).

A. Venturi. Teoria della bilancia di torsione di Eötvös. Estratto dagli Atti della R. Acad. di Scienze; Lettere ed Arti, Serie 3a, Vol. IX, Palermo, 1908.

O. Hecker. Die Eötvössche Drehwage des Kgl. Geodätischen Institutes in Potsdam. Verhandlungen der sechzehnten allgemeinen Conferenz der internationalen Erdmessung in London and Cambridge, 1909, part 2, pp. 310-318. Also appears in Zeitschrift für Instrumentenkunde, Jahrg. 30, pp. 6-14, 1910, and Sc. Abs., Vol. 13, 493.—O.

F. R. Helmert. Methode von Baron Eötvös zur Messung zweiter Differentialquotienten des Schwerepotentials. Encyklopädie der Mathematischen Wissenschaften, Band VI_{1B}, Heft 2, pp. 166-172, 1910.—O.

O. Eggert. Theorie und Andwendung der Drehwage von Eötvös. Zeitschrift für Vermessungswesen 42, pp. 474-483 and 505-17, 1913.

Theorie der Drehwage. Jordan's Handbuch der Vermessungskunde, 1923.

E. Soler. Primi Esperimenti con la bilancia di Eötvös; Memorie del Reale Instituto di Scienze, Lettere ed Arti, Vol. 28, No. 8, Venice, 1913.

H. von Böckh. Der Nachweis von Brachyantiklinalen und Domen mittelst der Drehwage. Zeitschr. Petroleum, Vol. XII, pp. 817-823, 1917.

K. Tangl. R. v. Eötvös zum Geburtstage, seine Untersuchungen über die Gravitation. Die Naturwissenschaften, Heft 30, July, 1918.

Versuche mit einer Drehwage, deren Gehänge in Wasser taucht. Math. u. Naturw. Anzeiger d. Akad. d. Wiss., Budapest, 43, pp. 342-356, 1926.

W. Schweydar. Die Bedeutung der Drehwage von Eötvös für die geologische Forschung nebst Mitteilung der Ergebnisse einiger Messungen. Zeitschrift für praktische Geologie-26, Heft 11, pp. 157-162, November, 1918. —G.

Die Drehwage und ihre Bedeutung für die Auffindung von Bodenschätzen. Die Naturwissenschaften, pp. 160-165, 1918.

Die photographische registrierende Eötvössche Torsionwage der Firma Carl Bamberg in Berlin Friedenau, Zeitschrift für Instrumentenkunde, Jahrg. 41, pp. 175-183, 1921.—O.

Die Photographisch Registrierung bei Feldmessungen mit der Eötvösschen Drehwage. Zeitschrift für Instrumentenkunde, Jahrg. 42, pp. 179-182, 1922.—O.

Über Fortschritte bei Feldmessungen mit einer Drehwage nach Eötvös. Zeitschrift für Instrumentenkunde, Jahrg. 43, pp. 307-311, October, 1923. —O.

Aufschlussmethode im Bergbau mit der Drehwage. Jahrg. d. Hallschen Verbandes für die Erforschung der Mitteldeutschen Bodenschätze und ihre Verwertung, Vol. 4, No. 2, pp. 352-368, Halle, 1924.

Die topographische Korrektion bei Schweremessungen mittels einer Torsionwage. Zeitschrift für Geophysik, I, pp. 81-89, 1924-5; and III, pp. 17-23, 1927.—O.

Eine neue Form der Drehwage. Zeitschrift für Geophysik, II, pp. 151-153, 1926.—O.

Bouasse. Geographie Mathematique, Paris, pp. 351, 1919.

Radò de Kövesligethy. Studi Vulcano Gravimetrici, pp. 13, and Geoide E Bilancia di Torsione, pp. 12, Bolletino della Societa Sismologica Italiana, Vol. XXII, fasc. 5-6, Anno 1919.—O.

E. Tams. Drehwage und Schweremessungen in ihrer Bedeutung für die Geologie. Geolog. Rundschau X, Heft 1, pp. 13, 1919.—O.—G.

A. Berroth. Eine vertikal schwingende Drehwage. Zeitschrift für Instrumentenkunde, 40, pp. 210-11, November, 1920. Sc. Abs., Vol. 24, 576—O.

Die Bestimmung der Gradienten der Schwere. Handbuch der Physik. (Geiger and Scheel), Band 2, pp. 465-475, 1926.—O.

R. Schumann. Über die Leistungen des Eötvösschen Schwerewagen. Östr. Monatschr. f. öffent. Baudienst U. Berg. u. Hüttenwesen, Vol. I, pp. 1-4, 1920.

Die Drehwage und ihre Verwertung zur Erforschung der Erdinnern. Mitt. Inst. Kohlvergassung, Wien, Vol. 2, p. 49, 1920.

Über die Genauigkeit der Messung mit der Drehwage. Zeits. f. Instrumentenkunde, 51, pp. 426-430, Aug., 1931. Sc. Abs., Vol. 35, 289.—O.

H. Gornick. Die Drehwage und ihre Anwendungen zu praktisch Geologischen Untersuchungsarbeiten; Erzausschusz, Bericht Nr. 2, Verein Deutscher Eisenhüttenleute, Sitzung vom 15 December, 1921, in Düsseldorf.

Walter D. Lambert. Some Mechanical Curiosities connected with the Earth's Field of Force. American Journal of Science, pp. 129-158, Sept., 1921. —O.—G.

The Tendency of elongated Bodies to set in the East and West Direction. Nature, Vol. 108, p. 528, 1921.—O.—G.

The Eötvös Balance. Bulletin of the National Research Council, Washington, Vol. 3, part 2, No. 17, p. 17, March, 1922.—O.—G.

The Eötvös Tortion Balance. Encyclopaedia Britannica, 14th Edition, Vol. 10, pp. 132-133, 1929.—O.—G.

Arthur Schuster, E. H. Grove-Hills, E. A. Reeves, and W. D. Lambert. The Tendency of elongated Bodies to set in the North and South Direction, Nature, Vol. 108, pp. 240, 403, 433, and 528, 1921.—O.—G.

A. Prey. Die Bestimmung des Geoides aus Schweremessungen. Einführung in die Geophysik, pp. 28-60, 1922.—O.

H. Shaw and E. Lancaster-Jones. The Eötvös Torsion Balance. Proceedings of the Physical Society of London, Vol. XXXV, pp. 151-165, 1923. Also the Application of the Eötvös Torsion Balance to the Investigation of local gravitational Fields, pp. 204-212. Sc. Abs., Vol. 26, 1728, 1729.—O.

The Eötvös Torsion Balance and its use in the Field. Nature, Vol. 111, pp. 849-851, 1923. Sc. Abs., Vol. 26, 2069.—O.—G.

The Eötvös Torsion Balance and its Application to the Location of Minerals. Mining Magazine, Vol. XXXII, pp. 18-25, 86-92, 1925. Reprinted in pamphlet form by L. Oertling, Ltd.—O.—G.

The Theory and Practical Employment of the Eötvös Torsion Balance. Mining Magazine, April to July, 1927. Reprinted in pamphlet form by L. Oertling, Ltd.—O.—G.

The Gravity Gradiometer. Mining Magazine, Vol. XL, pp. 272-279, May, 1929.—O.—G.

E. Lancaster-Jones. The Computation of Eötvös Gravity Effects. A.I.M.M.E. Technical Publication No. 75, pp. 25, 1928. Geophysical Prospecting, 1929, pp. 505-529. Ec. Geol. Bibl., Vol. I, 1651.—O.—G.

Searching for Minerals with Scientific Instruments. (A discourse given at the twenty-first annual exhibition of the Physical and Optical Societies). Journal of Scientific Instruments, Vol. VIII, No. 2, pp. 34-38, Feb., 1931. —O.

The Principles and Practice of the Gravity Gradiometer. Journal of Scientific Instruments, Vol. IX, No. 11, pp. 341-353; and No. 12, pp. 373-380, 1932.

H. Shaw. Local Variations of Gravity. Encyclopaedia Britannica, 14th Edition, Vol. 10, pp. 667-668, 1929.—O.—G.

Finding Minerals by Physical Methods. Discovery, Vol. 12, No. 136, pp. 120-124, April, 1931.—O.—G.

H. Shaw, J. McG. Bruckshaw, and S. T. Newing. Applied Geophysics. Board of Education, Science Museum, pp. 101, 1931.—O.—G.

G. P. Lenox Conyngham. The Eötvös Torsion Balance. The Observatory, Vol. XLVI, No. 591, pp. 239-243, August, 1923.—O.

James de Graaf Hunter. Measurements of the Rates of Change of Gravity. Glazebrook's Dictionary of Applied Physics, Vol. III, pp. 404-406, 1923.—O.

Stephen Rybar. The Eötvös Torsion Balance and its Application to the Finding of Mineral Deposits. Economic Geology, Vol. 18, pp. 639-662, 1923.—G.

Eine neue Konstruktion der Eötvösschen Drehwage. Math. Naturw. Anz., Budapest, (46), pp. 698-723, 1929. Ec. Geol. Bibl., Vol. 3, No. 1, 1022.

The Small Eötvös-Rybar Torsion Balance for automatic Registration. 10 pp. 1929. A Prospectus issued by Ferdinand Süss, Budapest. Ec. Geol. Bibl., Vol. 2, No. 2, 1375.

Emanuel Wagner. Prospecting with the Eötvös Balance. Engineering and Mining Journal-Press, Vol. 116, No. 14, pp. 583-589, October 6, 1923.—G.

I. Yamamoto. Observations on the Distribution of Gravity Gradients on Toné Basin. Report of the Imperial Japanese Geodetic Commission, Vol. 3, pp. 1-90, 1923.

C. A. Heiland. Die neue Drehwage der Askania-Werke. Zeitschrift für Feinmechanik und Präzision, Vol. XXXII, Heft 19, pp. 213-216, 1924.—O.

Instrumentelle Neuerungen auf dem Gebiet der angewandten Geophysik. Zeitschrift für Geophysik, Vol. 1, pp. 118-119, 1924-5.—O.

Die Brauchbarkeit von Drehwagen im Felde. Zeitschrift für Instrumentenkunde, Jahrg. 45, pp. 89-95, 1925.—O.

Instrumente und Methoden zur Ermittlung nutzbarer Lagerstätten. Zeitschrift für Instrumentenkunde, Jahrg. 45, pp. 417-436, Sept., 1925. (A few pages on Torsion balance).—O.

Instruments and Methods for the Discovery of useful Mineral Deposits. Engineering and Mining Journal Press, Vol. 121, No. 2, pp. 47-49, 56-57, Jan. 9, 1926.—O.—G.

Schweydar-Bamberg types of Eötvös Torsion Balance. Bulletin Am. A.P.G., Vol. 10, pp. 1201-1209, 1926.—G.

Geophysical Methods of Prospecting. Colorado School of Mines Quarterly, Vol. XXIV, No. 1, pp. 17-47, 1929.—O.—G.

Directions for the use of the Askania Torsion Balance, pp. 88, January, 1933.—O.—G.

C. A. Heiland and Dart Wantland. A selected List of Books and References on Geophysical Prospecting. School of Mines Quarterly, Vol. XXVI, No. 3, July, 1931.—O.—G. (Directions for use of the Askania Torsion Balance by Heiland, also contains a selected list on the Torsion balance).

V. Inglada. Los Observationes gravimetricas, Madrid, 1925 (596 pp.). Rev. d. l'Accad. Cien. exact., Madrid 21, pp. 169-184, 1924.—G.

Los Procedimientos geofisicos de prospection; II, El precedimiento gravimétrico. Ingeniaria y Construccion 6, pp. 225-231, 287-293, 361-368, 501-519, 1928.

K. Mader. Zur Verwendung der Drehwage von Eötvös bei nahen grossen Massen. Sitzungsber. d. Akad. Wiss. Wien, Math.-nat. Kl. Abt. IIa, 133, pp. 117-132, 1924.—G.

O. Meisser. Ermittlung der Tiefe von schwerestörenden Massen mittels Drehwage. Zeitschrift für Geophysik, Jahrg. 1, pp. 32-35, 1924.—O.

P. Nikiforov. Sur le variometre d'Eötvös. Accad. d. Sc. de Russie, C. R. de Séances de la Comm. sismiques permanente, T. VII, 3, p. 343, Leningrad, 1924.

Physical Principles of the Gravitational Method of Prospecting. (Russian with abstract in English). Bulletin of the Institute of Practical Geophysics, Leningrad, No. 1, pp. 153-257, 1925. Also No. 2, pp. 232-264,

1926. Translated into Spanish in Boletin Petroleo, Lima, Peru, Vol. 27, No. 4, pp. 467-483, April, 1929,—G.; and by Kazujin in Assoc. Geofisica, Mexico, Bol. 1 and 2, 1930.

A New Type of Short Period Gravity Variometer; The Physical Principles of the Gravitational Method of Prospecting. Third Pan-Pacific Sc. Cong., Tokyo, 1926, Proc., pp. 652-662, 1928.—O.—G.

Les principes Physiques de la méthode gravimetrique de prospection. Intern. Geol. Congress, 14th Session, Spain, 1926, Compt. Rend. (4), pp. 1589-1605, 1928. Ec. Geol. Bibl., Vol. 2, No. 1, 936.—G.

Sur un noveau type de variometre de gravité à courte periode. Intern. Geol. Congress, 14th Session, Spain, 1926, Compt. Rend. (4), pp. 1719-1726, 1928.—G. Appears in Russian also in Bulletin of the Institute of Practical Geophysics, Leningrad, No. 3, pp. 308-316, 1927. Ec. Geol. Bibl., Vol. 2, No. 1, 937.

W. H. Fordham. Oil Finding by Geophysical Methods. Journal of the Institute of Petroleum Technologists, Vol. 11, No. 52, pp. 448-470, October, 1925.—G.

Evolution of the Eötvös Torsion Balance, Oil News, (London), May 19, 1928. Ec. Geol. Bibl., Vol. I, 1581.—G.

Geophysical Surveying. Institution of Petroleum Technologists, Vol. 15, pp. 35-42, and 64, 1929.—G.

J. Koenigsberger. Ueber die heute mit der Drehwage von Eötvös bei Feldmessungen erreichbare Genauigkeit und über den Einfluss der geolgischen Beschaffenheit des Terrains herauf. Zeitschrift für Praktische Geologie, Jahrg. 33, Heft 11, pp. 169-175, 1925.—G.

B. Noumérov. Fondements théorétiques de l'application des méthodes gravimetriques à la géologie. Bulletins du Comité Géologique Leningrad XLIV, No. 3, pp. 331-347, 1925. (Russian with Abstract in French).—G.

M. Barandica, J. Garcia Sinerez, J. Milans del Bosch, R. Gil Y. G. Sans Huelin. Investigaciones Geofísicas en la cuenca potásica de Cataluña: Intern. Geol. Congress, 14th Session, Spain, 1926, Compt. Rend. (4), pp. 1653-1676, 1928. Ec. Geol. Bibl., Vol. 2, No. 1, 874.—G.

Hans Haalck. Ein neuer Drehwagetypus. Zeitschrift für Geophysik, Jahrg. 2, pp. 293-297, 1926.—O.

Die Gravimetrischen Verfahren der angewandten Geophysik. Sammlung Geophysikalischen Schriften von Mainka, No. 10, pp. 205, 1929.—O.

F. Haarstick. Die Drehwage und ihre Andwendung zur Erforschung der oberen Erdrinde. Mitteilungen aus dem Markscheidewesen, Freiberg, I Sa., pp. 56-71, 1926.

K. A. Kirillov. Convenient Methods for the Determination of $R_a\left(\frac{\partial_z W}{\partial y \partial z}\right)$ and $Q_a\left(\frac{\partial_z W}{\partial y^2} - \frac{\partial_z W}{\partial x^2}\right)$ in the case of inclined strata. Bulletin of the Institute of Practical Geophysics, Leningrad, No. 2, pp. 265-269, 1926.

R. Krahmann. Die Anwendbarkeit der Geophysikalischen Lagerstätten

Untersuchungsverfahren, insbesondere der elektrischen und magnetisschen Methoden. Abhandlungen zur praktischen Geologie und Bergwirtschaftslehre, Halle, pp. 40, Vol. 3, 1926, Chapter V, pp. 28-33 on gravitational methods.—O.

W. F. P. McLintock and J. Phemister. The Use of the Torsion Balance in the Investigation of Geological Structure in South-west Persia. Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for the year 1926, pp. 168-196.—O.—G.

Published by L. Oertling (author not stated). The Eötvös Torsion Balance (pp. 90). Reviewed in Nature, Vol. 118, p. 406, 1926.—O.—G.

A. Reinecke. Ueber eine neue kleine photographisch registrierende Drehwage nach Schweydar: Intern. Geol. Congress, 14th Session, Spain, 1926, Compt. Rend. (4), pp. 1707-1717, 1928.—G. Ec. Geol. Bibl., Vol. 2, No. 1, 946.

George Steiner. Torsion Balance Principles as applied by the original Eötvös Torsion Balance. Bulletin Am. A. P. G., Vol. 10, pp. 1210-1226, 1926.—G.

A. Belluigi. Sulla Bilancia di Eötvös. Bolletino della Societa Sismologica Italiana, 1927.

Su l'uso del variometro di gravita. L'Industria Mineraria, 1927.

Sulla "Curvatura Eötvössiana". Soc. Sismol. Ital., Bol. 28 (1-2), pp. 53-58, 1929. Ec. Geol. Bibl., Vol. 2, No. 1, 879.

Gravimetria Mineraria. L'Industria Mineraria Roma, pp. 75, 1929. Ec. Geol. Bibl., Vol. 2, No. 2, 1369.

F. Hopfner. Die Methode von Eötvös zur Messung zweiter Ableitungen der Kraftfunction der Erde, Figur der Erde, pp. 101-107, 1927.—O.

Die Eötvössche Schwerewage und ihre Eignung für die praktische Geologie. Zeitschrift d. Österr. Ing.-u. Architektenvereins, 1927.

Karl Jung. Die Bestimmung von Lage und Ausdehnung einfacher Massenformen unter Verwendung von Gradient und Krümmungsgrösse. Zeitschrift für Geophysik, Jahrg. 3, pp. 257-280, 1927; Jahrg. 4, p. 48, 1928; Jahrg. 5, pp. 238-252, 1929.—O.

Bemerkungen zur numerischen und graphischen Behandlung der Krümmungsgrösse. Zeitschrift für Geophysik, Jahrg. 4, pp. 313-317, 1928.—O.

Gravimetrische Methoden der angewandten Geophysik. Handbuch der Experimentalphysik, Vol. 35, part 3, pp. 48-208, 1930.—O.

Karl Kilchling. Die Gleichmässig gedrehte Drehwage. Zeitschrift für Geophysik, Jahrg. 2, pp. 134-137, 1926; and Jahrg. 3, pp. 281-285, 1927.—O.

Eric Pautsch. Methods of Applied Geophysics (pp. 82), Houston, Texas, 1927; (pages 7-25 on torsion balance and gravitational method).—O.—G.

Sineriz, D. Jose Garcia. Metodo de la balanza de torsion de Eötvös. Revista Minera, Metalurgica y de Ingeneria, 1927.

Richard Ambronn. Elements of Geophysics (original, and translation by Margaret C. Cobb), Chapter II, pp. 8-59, 1928. Ec. Geol. Bibl., Vol. 1, 1535.—O.—G.

Donald C. Barton. The Eötvös Torsion Balance Method of Mapping Geologic Structure, New York Meeting, A.I.M.E., Feb. 1928. Appears as Technical

Publication No. 50, and in Geophysical Prospecting, pp. 416-479, 1929. Ec. Geol. Bibl., Vol. 1, 1546.—O.—G. Terrestrial Magnetism, Vol. 33, No. 3, pp. 141-142, Sept. 1928. Ec. Geol. Bibl., Vol. 1, 1546 and 1549.—O.

The Torsion Balance in the Determination of the Figure of the Earth. American Journal of Science, pp. 149-154, August, 1929. Sc. Abs., Vol. 33, 541.—O.—G.

Gravity Measurements with the Eötvös Torsion Balance. Bulletin of the National Research Council, Washington, No. 78, pp. 167-190, 1931. Sc. Abs., Vol. 34, 2186. Ec. Geol. Bibl., Vol. IV, No. 1, 895.—O.—G.

Eötvös Torsion Balance. Physics, Vol. 3, No. 1, pp. 29-38, July, 1932.—O.

J. H. Jones and R. Davies. The Measurement of the second Derivatives of the gravitational Potential over a buried Anticline. Monthly Notices of the Royal Astronomical Society, Geophysical Supplement, Vol. II, No. 1, pp. 1-32, May, 1928. Ec. Geol. Bibl., Vol. I, 1632.—O.

J. A. A. Mekel. Theorie van het tektonisch gravimetrisch Onderzoek, Delft, Holland, 1928. Also translation by M. Walter Pesman, Colorado School of Mines.—O.—G.

A gravitational Survey over the Fault Zone of Heerlerheide, in the mining district of southern Limburg, Nederland. Mijngebied te Heerlen, Geol. Bur. Jaarverslag, 1928, pp. 139-152, Heerlen, 1929. Ec. Geol. Bibl., Vol. 3, No. 2, 1013.—G.

W. P. Jenny. Neuerung an Drehwaagen. Z. Prakt. Geol., Jahrg. 36, Heft 9, pp. 141-143, Sept., 1928. Ec. Geol. Bibl., Vol. I, 1631.—G.

C. Tsuboi. A Gravity Variometer made of vitreous Silica. Imp. Acad. Tokyo, Proc. 4, pp. 300-302, June, 1928. Sc. Abs., Vol. 31, 2881.—O.

Luis Urquijo. Estudio de la teoria de la balanza de torsion. Bol. Petr., Lima, Peru, 26 (4-5), pp. 400-406, Oct.-Nov., (6), pp. 614-621, Dec., 1928.

Estudio de la teoria de la balanza de torsion. Bol. Petr., Lima, Peru, 27 (1), pp. 11-14, 1929.—G.

John H. Wilson. Geophysical Prospecting. The Colorado School of Mines Magazine, 1928 (Part 3, 7 pages on torsion balance). Ec. Geol. Bibl., Vol. I, 1733.—O.—G.

H. Winkelmann. Über die Praktische Verwendbarkeit verschiedener Drehwagentypen, insbesondere der Haff-Drehwage. Gerlands Beiträge zur Geophysik, Vol. 19, pp. 321-333, 1928. Ec. Geol. Bibl., Vol. I, 1734.—O.

Manuel Archila. Metodos Geofisicos: balanza de torsion. Bol. Minas Petr., Bogota, 1 (4), 305-313, Apr., 1929. Ec. Geol. Bibl., Vol. 2, No. 1, 870.—G.

E. A. Ansel. Geophysikalische Aufschliessungsmethoden. Chapter 53, Lehrbuch der Geophysik von Gutenberg, pp. 517-552, 1929.—O.

Theorie der gravimetrischen Aufschlussmethoden-Schwerevariometer. Handbuch der Geophysik von Gutenberg, Band VI, Lieferung 1, pp. 195-235, 1931.—O.

A. S. Eve and D. A. Keys. Applied Geophysics, Chapter V, pp. 149-182, 1929.—O.—G.

Edith A. Nelson. The Effect of Stratification on the Gravity Gradient and the

Curvature of the Level Surface. Phil. Mag. 7th series, Vol. 10, pp. 513-516, Sept., 1930. Sc. Abs., Vol. 34, 387. Ec. Geol. Bibl., Vol. 4, No. 1, 911.—O.—G.

A. B. Broughton Edge and T. H. Laby. The Principles and Practice of Geophysical Prospecting. Report of the Imperial Geophysical Experimental Survey 1931, pp. 135-172, 299-317. Ec. Geol. Bibl., Vol. 4, No. 1, 818.—O.—G.

A. O. Rankine. On the Representation and Calculation of the Results of Gravity Surveys with Torsion Balances. The Proceedings of the Physical Society, Vol. 44, part 4, No. 244, pp. 465-473, July 1, 1932.—O.

Some Observations with a Gravity Gradiometer. The Proceedings of the Physical Society, Vol. 44, part 4, No. 244, pp. 474-493, July 1, 1932.—O.

Some Aspects of Applied Geophysics. Nature, Vol. 130, pp. 421-423, Sept. 17, 1932.—O.

M. M. Slotnick. Curvature of the Equipotential Surfaces. Bull. Am. A.P.G. Vol. 16, No. 12, pp. 1250-1259, Dec., 1932.—O.—G.

O. F. T. Roberts. The Connexion between the Eötvös Magnitudes. Nature, Vol. 130, No. 3272, p. 94, July 16, 1932.—O.—G.

Torsion Balance Work in Canada

With the exception of the publication by Eve and Keys none of the publications dealing with the torsion balance in Canada contain anything beyond a very elementary explanation of the theory of the instrument. As it may be of interest to some readers to know what has been done in Canada with the instrument a list of publications dealing with the subject is given below.

The first investigations were begun by the Dominion Observatory in the autumn of 1923 with two instruments which had been obtained in 1922 from O. Hecker of Jena. Unfortunately these were found unsatisfactory and had to be returned to Germany to be altered. Owing to a number of reasons and delays the alterations were not completed until 1928 when the instruments were finally put in working condition.

In 1928 an arrangement for a joint investigation of the application of the instrument to geological problems in Canada was made between the Observatory and the Geological Survey and a Süss and an Askania instrument were purchased for the purpose. The investigation was continued until the end of 1930 when it was temporarily discontinued owing to lack of funds. During 1931 the Observatory carried on a joint investigation with the Ontario Research Foundation in the lignite field of Northern Ontario. A report on the work in Northern Ontario has been prepared and is expected to appear in print shortly.

As far as the writer knows the first torsion balance survey in Canada was that in 1927 of the Falconbridge ore body, near Sudbury, by the Prospecting Co. represented by Dr. Max Mason. Surveys were also made in Western Canada during the season of 1930 for the Hudson's Bay Oil and Gas Co. but no report on the work has been published.

Max Mason. Geophysical Exploration for Ores. A.I.M.E. Tech. Pub. 45, p. 26 and p. 28, Geophysical Prospecting, 1929. This paper also appears in the numbers of Nov. 12 and 19, 1927, of the Engineering and Mining Journal. (See also Ec. Geol. Bibl., Vol. 1, 1666).—G.

A. H. Miller. Gravitational Methods of Geophysical Prospecting. Canadian Mining Journal, Vol. XLIX, No. 24, pp. 476-481, June 15, 1928. Ec. Geol. Bibl., Vol. 1, 1667.

Torsion Balance Surveys of the Hull-Gloucester and Hazeldean Faults. Memoir 165, Studies of Geophysical Methods 1928 and 1929, Geological Survey of Canada, pp. 197-209, 1931. Ec. Geol. Bibl., Vol. 4, No. 2, 1074.

Surveys with the Torsion Balance and the Magnetometer in Eastern Canada. Journal of the Royal Astronomical Society of Canada, Vol. XXVI, No. 1, pp. 1-16, 1932.

Gravitational and Magnetometric Investigations. Memoir 170, Studies of Geophysical Methods, 1930, pp. 99-118, Geol. Sur. of Canada, 1932.

G. S. Hume. Gravitation. Prospecting in Canada by officers of the Geological Survey, Economic Geology Series No. 7, pp. 207-210, 1930.

REVIEW OF PUBLICATIONS

The Calculus of Finite Differences, by L. M. Milne-Thomson, XXIII plus 551 pages, 5½ x 8¾ inches. Macmillan and Co., 1933, price 30 shillings.

The methods of finite differences and numerical mathematical analysis are to a large extent neglected in university curricula. Possibly this is because the subject is far from elementary. The numerous applications of the methods justify more attention being paid to it than is at present the case at least in the universities of this country. The author has written a very comprehensive treatise on the subject.

The first seven chapters deal with the methods of interpolation and this part of the book can be followed without advanced mathematical knowledge but will not be found easy reading. The latter part of the book deals with difference equations. The book will be found difficult for the beginner and should be preceded by some more elementary book on the theory of interpolation and mechanical quadratures. With some general knowledge gained from such a preliminary course, the reader will better appreciate the powerful methods of analysis which have been elaborated and cannot fail to have his outlook broadened. Everyone interested in the subject of numerical mathematical analysis should obtain a copy of the book.

The publishers have taken great pains in setting up the numerous mathematical symbols and formulae in clear and orderly type and this is especially the case where heavy or bold letters are required. Too often these are not sufficiently accentuated to avoid confusion at times in the reader's mind. The book is well bound.

R. K. Y.

A Ready Reference Handbook of the Solar System, by W. G. Colgrove, M.A., B.D. 150 pages, 4½ × 6 in., with 9 figures. London, Ont., published by the author, 1933. Price $1.00.

Those who have been reading this JOURNAL for a number of years will recall the series of articles dealing with the several members of the solar system which were contributed by Mr. Colgrove. He has now brought them together, has made additions and revisions, and has published them in a little volume convenient for the pocket or to have near for reference. The book is dedicated to the amateur astronomers and is intended for them. It has not the fullness or the precision desired by the professional astronomer. The layman with a taste for science, will undoubtedly find pleasure in considering the thousand interesting items in the book.

C. A. C.

The Composition of the Stars, being the Halley Lecture delivered on June 1, 1933, by Henry Norris Russell.

The Place of Observation in Astronomy: an inaugural lecture delivered before the University of Oxford on April 28, 1933, by H. H. Plaskett.

These are two 32-page pamphlets printed at the Oxford University Press whose Canadian branch is on University Avenue, Toronto. Price of each, 60 cents.

In the first pamphlet Professor Russell essays the difficult task of summarising the great mass of experimental and theoretical results which have been produced in recent years in the attempt to solve the nature of the stars. The qualitative analysis is first given and then follows the quantitative application to the problem of the numerous data obtained from spectroscopy and atomic physics.

In the second pamphlet is the very appropriate address by Professor Plaskett, on his undertaking the duties of the Savilian professorship which was founded three hundred years ago. He quotes Sir Henry Savile's statement of the duties attached to the position:

> Upon the Professor of Astronomy I also lay this injunction that, following the example of Ptolemy and Copernicus and treading in their footsteps, he shall make astronomical observations both by night and by day, proposing suitable instruments for this purpose and selecting a convenient plan and convenient seasons. . . . . And I trust that in this matter the University will abundantly

furnish all help and assistance, since this is the only true method by which ancient Astronomy can either be confirmed or corrected.

Professor Plaskett discusses, in a very clear and well-ordered way, modern astronomical investigations, the nature of astronomical theories, and the conditions for effective observation; and shows that observation and theory have played roughly equal but complementary parts and must progress together.

It is pleasing to learn that Oxford University has authorized the expenditure of £2,400 for a solar telescope giving a stationary image of the sun ten inches in diameter and a powerful spectroscope for the study of the resulting solar radiation.

Professor Plaskett's numerous friends in Canada will wish him success in his researches.

C. A. C.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

NOTE BY THE EDITOR

Dr. P. M. Millman, of the University of Toronto, has consented to take charge of a new department in the JOURNAL, in which will be reported matters of interest in the field of meteoric phenomena. He will be glad to receive reports of observations.

THE GEMINID METEORS

The appearance of the Geminids in 1933 once more demonstrated the fact that this shower is a reliable one, well worth carefully planned visual and photographic observations. At the David Dunlap Observatory* observations were scheduled for the nights of December 11-12, 12-13, 13-14. December 11-12 was clear and cold and a party of five observed 307 meteors between 9 p.m. and 3 a.m. The majority of these meteors were Geminids and seven of them were estimated to be brighter than zero magnitude, the brightest being magnitude −3. Exposures totalling 17h 49m were made on three meteor spectrographs but no meteor spectra were photographed since the brightest meteors appeared just outside the fields covered by the cameras. Total exposures of 11h 35m were made on two direct cameras and three Geminid trails were photographed, the three meteors having estimated magnitudes of −2, 1, and 0 respectively. December 12-13 was cloudy. The sky cleared for a short time on the following night but hazed over five minutes after exposures had started. That the shower was still active on December 13-14 was evidenced, however, by the fact that a dozen meteors were seen on the ten-minute walk from the highway in to the observatory.

At the Harvard Observatory stations near Cambridge, Mass., the regular patrol cameras photographed four Geminids. One of these was brighter than magnitude −4 and was photographed by two cameras at the Oak Ridge station and by one at the Cam-

*Fifteen miles north of Toronto; lat. 43° 51.′8 N, long. 79° 25.′3 W.

bridge station. These three photographs are probably the best material that has yet been obtained for extremely accurate height computation. They are being investigated by Dr. W. J. Fisher of the Harvard Observatory. Dr. Fisher points out that, taking the AI series of patrol plates of the Harvard Observatory (1901-1933), we find that one out of every six or seven plates exposed on the night of the Geminid maximum shows a meteor trail. This is an extremely high percentage.

Red Plates for Meteor Photography

It is certain from visual observations of meteor spectra made during the latter part of the nineteenth century that strong lines in the red are of common occurrence. Our knowledge of meteor spectra in the blue and violet wavelengths does not make it possible to decide definitely what these red lines are and a good photographic meteor spectrum extending to λ 6500 or beyond is the only solution. During the observations of the Leonids and Geminids in 1933 Eastman IC Special Spectroscopic plates were tried out. These have a maximum of sensitivity at about λ 6200 and proved to be very sensitive not only in the red but in the blue as well. They are probably the best plate yet developed for attempting to photograph meteor spectra in the red.

Another very interesting unexplored region in meteor spectra is that near λ 8600. Three strong ultimate lines of ionized calcium occur here and these are very similar in their behaviour to the H and K lines. Since the latter are the strongest feature of meteor spectra it is possible that the lines at λ 8600 also appear. A plate very suitable for photography in this region is the Eastman IP Spectroscopic plate.

P.M.M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Association of Lundin with Warner and Swasey

The Warner and Swasey Co. of Cleveland announces that Mr. C. A. Robert Lundin is now associated in its optical department. Two outstanding achievements of this company are the mountings of the great refractors of the Lick and Yerkes observatories. The objectives of these instruments, of apertures 36 and 40 inches, respectively, were ground and polished by Alvan Clark and Sons and their perfection is due in considerable degree to the skill of C. A. Lundin, one of their workmen. It is his son who is now associated with the Cleveland firm. For some years he has been engaged in optical work, one of his productions being the photographic doublet with which Pluto was discovered at the Lowell Observatory. This lens was left in an unfinished condition by J. H. Metcalf and it was refigured and polished by Mr. Lundin.

To the Warner and Swasey Co. has been awarded the contract for the 80-inch reflector for the McDonald Observatory of the University of Texas.

Wonders of Nature

We are accustomed to the frequent reports of remarkable new discoveries in the inanimate realms of physics and astronomy, but to the present writer some exceptional phenomena in animated nature are much more startling.

There has just appeared a new life of Thomas Young (1773–1829), one of the greatest of English scientists. He was one of the real founders of the wave theory of light and also the first to supply the key to the deciphering of Egyptian hieroglyphics. His childhood was remarkable. He could read fluently at two and at four had read the Bible through twice. At twelve he had mastered most of the classical and modern languages, and was a student of Persian, Syriac and Chaldean. At the same time he had acquired a profound acquaintance with the science of his time; yet he grew up with unimpaired physical and intellectual powers and was a tireless investigator to the day of his death.

In this connection one is reminded of William Rowan Hamilton (1805–1865). At five he could read Greek, Latin and Hebrew, and throughout his life he possessed one of the most original and powerful minds. At the age of 17 he undertook to read Laplace's "Mécanique céleste" and actually detected an error in it. At 22, before he had graduated at the University, he was made Andrews Professor of Astronomy at Dublin. Later he invented the method of quaternions. It is refreshing to learn that although he had such extraordinary mental activity when a child he was a real infant and would cry if he was annoyed or could not have his own way.

Another wonder of nature, and of quite a different kind, was reported in the *Scientific American* for December, 1933. A workman, while excavating at the General Electric Works in Schenectady, came upon several leopard frogs embedded in the solid soil at a distance of ten feet below the surface of the pavement. They were dug out by the fingers and tossed aside as certainly dead, but an hour later the workman was amazed to see them moving and actually trying to climb the wall of the excavation. Knowing the date when the nearby building was erected and the pavement laid it was deduced that the frogs had been held in the soil for 34 years. They were true Rip Van Winkles.

On relating this incident to a colleague he expressed strong doubt as to the truth of the story. The only answer required was that it was given with photographs and all details in the above mentioned magazine which is the sworn enemy of all scientific tricksters or fabricators.

When beggars die, there are no comets seen;
The heavens themselves blaze forth the death of Princes.

Until recently Lhasa, the capital of Tibet, was strictly a "forbidden city" and no foreigner was allowed to enter it. A few venturesome explorers had managed to visit the place but only under some disguise. However, in the World War, the Tibetan government offered a thousand soldiers to fight on the British side, and in 1922 Lhasa was linked to India by telegraph. Hence, when the Dalai Lama, the chief ruler of Tibet, died on December 17 last, the news was soon given to the world.

A few days later there appeared in the newspapers the following dispatch:

> Peiping, China, Dec. 21, 1933.—Accompanied by a natural phenomenon which made the occasion more impressive, followers of the Dalai Lama, who died mysteriously at Lhasa, capital of Tibet, last Sunday, performed the weird mourning rites of their religion.
>
> Garbed in the ancient robes of the order, the monks went through all the chants and precise actions of the ritual before the "True Sacred Replica" of Lhasa's Potala palace where the Dalai Lama died.
>
> As the ceremony was in progress the new moon successively eclipsed Venus and then Saturn, after which an unusual constellation was seen in the heavens. The incident was regarded by the faithful as an omen caused by the death of the spiritual head of their religion.

The reference in the last paragraph is to the occultation of Venus and Saturn by the moon. From the OBSERVER'S HANDBOOK it is found that on December 20th at 2.04 a.m., 75th meridian time, the moon was in conjunction with Venus, the centre of the planet being 0°43′S. of the centre of the moon, as viewed from the centre of the earth. An hour and eleven minutes later, i.e. at 3.15 a.m., the moon came into conjunction with Saturn, the latter being 0° 10′ S. of the former. At these hours the moon was below the horizon of Toronto. It occurred to the present writer to look into the circumstances at Lhasa. That city is in long. 6h. 4m. E. of Greenwich, and lat. 29° 39′ N. Hence the conjunction with Venus would be at about 1.08 p.m., December 20; that with Saturn at about 2.09 p.m. On examining the conditions for occultation it is found that both planets were occulted by the moon but in broad daylight early in the afternoon. At Peiping the occultation of the planets would take place about 1 h. 42 m. later than at Lhasa, or in daylight also. How the phenomena described in the dispatch could be seen by the mourners at the burial of the deceased ruler is surely a problem.

C. A. C.

MEETINGS OF THE SOCIETY

AT OTTAWA

March 10, 1933.—This was the third public lecture of the season at the Victoria Memorial Museum. The president, Mr. R. Glenn Madill, was in the chair.

The subject was "The International Polar Year 1932-1933, its Organization and Purposes", and the lecturer was Mr. John Patterson, Director of the Meteorological Service of Canada. A summary of Mr. Patterson's talk follows:

The first International Polar Year was organized largely through the influence and inspiration of Lieut. Carl Weyprecht of the Austrian-Hungarian navy, as a result of his experience in the arctic regions when Franz-Josef Land was discovered in 1873-74. The idea underlying the first International Year was to send small parties to as many places as possible that were fairly accessible in the polar regions, and altogether some twelve nations established fourteen stations.

Their programme included terrestrial magnetism, the aurora, and meteorology, but in those days there were no self-recording instruments, and visual observations only were taken.

Britain and Canada selected Fort Rae as the base of their operations, since it was the farthest north of the Hudson Bay posts from which it would be possible for the party to return at the close of the year without having to spend another winter in the north.

The first International Polar Year was a distinct triumph of international co-operation, and was abundantly successful, so that Vice-Admiral Dominik of the Deutsche Seewarte at Hamburg, suggested that the most appropriate way to commemorate the first International Polar Year was to repeat it.

The project was formally authorized at the Conference of Meteorological Directors, held in Copenhagen in September, 1929, and Dr. LaCour, Director of the Danish Institute, was made president of the Commission. The aims were much the same as before, that is, to send small parties to the polar regions at as many places as possible, and to take observations throughout one complete year, from the 1st of August, 1932, to the 31st of August, 1933. With however the advent of self-recording instruments, all stations were to be equipped as far as possible with autographic instruments, and in order that their records might be published in a form that would be accessible to all scientific workers, it was decided to have the records on standard forms.

In the first International Polar Year it of course was not possible to obtain synchronous observations throughout the world, on account of the difficulties with time, but the radio has changed all that, and as a result, definite observations are taken on definite days throughout the year. The programme again consisted of observations in terrestrial magnetism, the aurora, and meteorology.

The magnetic stations were chosen chiefly with reference to their distribution in regard to the magnetic elements. For the aurora it was hoped to obtain a chain of observations that would encircle the polar regions, and at the same time from a sufficient number of stations, so as to determine the height. In Meteorology not only surface observations were to be taken, but observations in the upper air by means of pilot balloons to obtain wind direction and velocity, kites and aeroplanes, to get the temperature and pressure in the lower levels, and radiosonde instruments equipped with radio sending apparatus to obtain temperatures and pressure up to the greatest height it was possible to get the instruments, and radiation, fog, clouds, etc., were all to be made a special study.

Arrangements were also made whereby the observations at selected observing stations throughout the world could be made to fit in with the programme of the International Polar Year. As a result some 27 nations are participating in the project. Britain has re-occupied Fort Rae, while Canada has a chain of stations along the arctic circle, at Cape Hope's Advance, Chesterfield Inlet, and Coppermine, with special equipment at the permanent magnetic observatory at Meanook, Alta. The largest party is at Chesterfield Inlet, where they are equipped for taking magnetic, auroral, and meteorological observations. They have also equipment for measuring earth currents, potential gradient, and spectrographs to obtain the spectra of the aurora at various heights, and in addition to the panchromatic plates they are also using infra-red. Both Coppermine and Chesterfield Inlet are equipped for obtaining the temperature gradient at the top and bottom of the radio mast, with kites for the determination of temperature changes in the lower levels, for pilot balloon observations, and at Coppermine, with radiosonde instruments.

The magnetic autographic instruments are those designed by Dr. LaCour, and are used at practically all the special observatories in the arctic.

The reports from our own Canadian stations to date have been that they have been kept exceptionally busy with their work, and are obtaining very valuable data in all branches. From the magnetic and auroral side it is hoped that very great practical and theoretical results will be obtained, as these observations being complete throughout the whole year at so many places will enable investigators to refer to them in connection with so many of their problems for very many years to come. New magnetic maps of the polar regions will be constructed. One of the great meteorological problems that is facing meteorologists at the present time is that of the circulation of the atmosphere, especially in the polar regions. The scientists have gone forth equipped with all the latest and best devices for exploring the atmosphere to great levels, and it is hoped that very important results will be obtained from their endeavours. As the years go on, these observations will become more and more valuable. Other international expeditions have been of great scientific value in the results that have been achieved. This is the most complete international undertaking yet organized for the study of meteorological, magnetic and auroral problems, and it naturally follows that the results from it will be of greater importance than any that have preceded it.

Mr. Patterson's talk was illustrated by means of lantern slides. On behalf

of the society a vote of thanks was passed to the lecturer for his interesting address.

March 23, 1933.—This was the third of a series of informal technical talks at the Dominion Observatory. The president, Mr. R. Glenn Madill, was in the chair.

Mr. R. Meldrum Stewart, Director of the Dominion Observatory, was the speaker of the evening, and his talk was entitled "The Mathematical Theory of the Foucault Pendulum".

As the subject was treated in detail, it was impossible to deal with it in the short time available, and it was concluded at a meeting the following week.

In view of the highly technical nature of this topic, it seems wiser to leave the publication of a full account to Mr. Stewart.

MIRIAM S. BURLAND, *Secretary.*

AT EDMONTON

October 11, 1932.—The first autumn meeting of the Edmonton Centre was held in Room A 142 of the University at 8.15 p.m. The President, Dr. J. W. Campbell was in the chair.

The program opened with a short but interesting talk by Mr. W. E. Rose on Halley's comet. Mr. Rose was in South Africa in 1910 and he told of his experiences of this wonderful object as viewed there.

Professor Keeping then took the chair and Dr. Campbell gave a report of his journey east to see the eclipse of August 31. He had gone to Magog to join many others there, but clouds intervened at the critical time. The report was thus largely one of the personnel of the scientific expeditions that were gathered there and of some of the projects contemplated.

At the close of the meeting refreshments were served in A 111.

November 8, 1932.—The November meeting was held in A 142 with Dr. Campbell presiding.

After some matters of business were dealt with, a ten minute talk on Perseus and a few of the surrounding constellations was given by Mr. J. G. Taylor.

The main speaker of the evening was Mr. Robert Chambers whose subject was "Light Houses of the British Isles". Preceding the reading of his very interesting paper Mr. Chambers showed a number of slides of different light houses and of the various types of instruments and lanterns employed there. He had himself spent many years in one of these light houses before coming to Canada and his description of them contained many interesting personal experiences.

At the close of the meeting refreshments were served as usual.

December 13, 1932.—The first annual meeting of the Edmonton Centre was held at the Corona Hotel in the form of a dinner meeting and a large number of members together with their friends attended. Dr. Campbell presided.

Preceding the reports of the Secretary and the Treasurer, and the election of officers for 1933, the following new members were elected to membership:

Miss E. G. Buchanan, 15 Lemarchand Mansions, Edmonton.
Miss M. O. Buchanan, 15 Lemarchand Mansions, Edmonton.
Dr. A. J. Cook, University of Alberta, Edmonton.

At the suggestion of Mr. M. J. Hilton it was decided to send a letter conveying the season's greetings to Dr. J. M. Stagg and the other members of the Second Polar Year Expedition at Fort Rae, and a sheet was circulated for the signatures of those present to accompany the letter.

The main part of the program was an account of the life of Tycho Brahe by Mr. A. B. McKim. The experiences and life work of this great contributor to the development of science were very vividly portrayed, many personal touches being interspersed to give a human as well as a scientific interest.

On the whole, the holding of the annual meeting as a dinner meeting was felt to have been a decided success.

January 12, 1933.—The meeting was held in room A 142 of the University with Professor Keeping in the chair.

The following was elected to membership:

Mrs. E. Wyman, 9938, 115th Street, Edmonton.

The question of the best day for regular meetings was discussed and it was decided to continue with the second Thursday in the month.

Mr. Hilton took the chair, and Professor Keeping gave an address on "The Calendar". He spoke of the fundamental difficulty of reconciling solar and lunar times and of the various attempts that have been made to create workable calendars. He discussed the historical origin of the inconsistencies in our present calendar, and the case for reform, indicating the merits for many practical purposes of the 12-month uniform quarter scheme. He also showed in detail how the date of Easter is arrived at for any year of the Gregorian calendar.

After some discussion, the meeting adjourned for refreshments.

February 9, 1933.—The meeting was held in A 142 of the University with Professor Keeping in the chair.

The following new member was admitted to the society:

Mr. W. A. McAulay, 12907, 103 Ave., Edmonton.

Mr. Rupert F. Warren gave a ten-minute talk on Orion, after which the paper of the evening was given by Mr. C. Constantinescu on "The Rocket". Mr. Constantinescu gave a very interesting description of the various devices that have been suggested for making a journey out into space from the earth. The magnitude of the problem of getting out through the earth's atmosphere and of attaining a speed sufficient to overcome the retardation due to the earth's gravitational pull was discussed, and the paper closed with the description of a hypothetical visit to the moon which might be made when the departure from earth had been accomplished.

At the close of the meeting refreshments were served.

March 9, 1933.—The meeting was held in A 142 of the University with the president, Professor Keeping, in the chair.

The preliminary short talk was given by Dr. Campbell who explained some of the terms which are used in the HANDBOOK.

The main address of the evening was then given by Mr. F. S. Simpson whose subject was "The Planets". Mr. Simpson spoke on many aspects of the subject, but devoted himself principally to the character of the orbits, Kepler's law of areas, the perturbations caused on one another by the planets, and similar ideas. He used many ingenious devices, both geometrical and verbal, to make his ideas clear to the audience.

The meeting concluded with refreshments.

April 13, 1933.—The meeting of the Edmonton Centre was held in room A 142 of the University. The President, Professor Keeping, occupied the chair.

A short talk on "Stellar Magnitude" was first given by Dr. Campbell, after which the paper of the evening was given by Dr. E. H. Gowan on the subject of "Sun Spots". The speaker gave some general information about the sun's size, layers, and surface, and then went on to describe the structure of the surface in more detail. Sun spots were discussed historically and an account of their discovery and interpretation was given. A brief account of the spots was given from the following points of view: dimensions, duration, development, motions, distribution over the surface, temperatures, magnetism, and periodicity. The observed relationship between sun spots, terrestrial magnetism, radio reception, auroral activity and meteorological conditions were summarized. The spectroscopic evidence was reviewed, and the paper closed with a reference to the theories which attempt to explain the formation and maintenance of sun spots.

May 13, 1933.—The final meeting for the spring term was held in room 142 of the Medical Building of the University, and was presided over by Professor Keeping.

The Edmonton Centre was fortunate in having been able to obtain as speaker Dr. J. A. Pearce of the Dominion Astrophysical Observatory at Victoria, B.C. Dr. and Mrs. Pearce were on their way east and it was with great pleasure that they were entertained for a day as guests of the society in Edmonton.

Dr. Pearce prefaced his address with greetings from the Centres at Victoria and Vancouver. He also gave a historical sketch of the parent society from its inception in 1867, and this was especially interesting to Edmonton, the youngest centre.

The subject of Dr. Pearce's address was "The Diffuse Matter in Space". The lecture was well illustrated by slides and dealt with the dark clouds of galactic nebulae. Particular reference was made to the motions and distribution of interstellar calcium, a phase of the subject on which Dr. Pearce and Dr. J. S. Plaskett have done much work in recent years at Victoria. Dr. Pearce gave some of the results of their most recent investigations and these were very interesting. He pointed out that one important consequence was a large reduction in the estimated size of our galaxy that has hitherto been accepted.

At the conclusion of the address the thanks of the meeting were expressed

by Mr. Higinbotham, and adjournment was made for refreshments at which those present had an opportunity of meeting Dr. and Mrs. Pearce.

October 12, 1933.—The opening meeting for the fall term was held in A 142 of the University with the President, Mr. Keeping, in the chair.

The President welcomed the old members and visitors, and also Mr. Cyril Ellis who had formerly been a member at Battleford and who on his removal to Edmonton wished to be attached to the Edmonton Centre.

Mr. Harvey Wright of Drumheller was duly elected to membership.

The ten minute talk of the evening was given by Mr. Ralph McGibbon, who told how to identify the constellation Capricornus. He pointed out that this constellation has at the present time the double interest of being a constellation of the zodiac and also the location of the planet Saturn.

The paper of the evening was given by Dr. J. W. Campbell on "How the Diameters of Stars are Measured." The measurement by means of the interferometer was first described. The principle of the interferometer was explained by means of blackboard drawings and by lantern slides, and the way in which it can be used to measure the angular separation of double stars and the diameters of stars of known distance was shown.

The speaker then explained how the diameters can be calculated because of the relation which exists between temperature, diameter and absolute brightness.

After some discussion at the close of the paper the meeting adjourned for refreshments.

November 9, 1933.—The meeting was held in A 142, with Professor Keeping presiding.

The following five new members were admitted:

Mr. H. J. Brooks, 11537, 74 Ave., Edmonton.
Mr. W. H. Tucker, 10701, 81 Ave., Edmonton.
Mr. B. H. Backus, 10706, 69 Ave., Edmonton.
Mr. O. W. Colley, Castor, Alberta.
Mr. F. Fulmer, Edson, Alberta.

A short talk was then given by Dr. Campbell on how to estimate the time from circumpolar stars on a clear night. It was shown how the west star of Cassiopeia can be especially easily used for this purpose.

The principal speaker of the evening was Mr. M. J. Hilton, who chose as his subject "The Life and Work of Kepler". Mr. Hilton pointed out the great significance of Kepler's laws of planetary motion and explained how his work complemented the careful observations of Tycho Brahe. The contrast in the natural abilities of these two great men was pointed out, Tycho being extremely able in observing work and in the manipulation of mechanical devices though relatively weak in analysis, while just the reverse was true of Kepler. A very vivid picture was drawn of the devotion and persistence of Kepler in obtaining the laws which bear his name, in spite of repeated failures and in spite of a frail physical constitution.

At the close of the meeting a pleasant social time was spent during the serving of refreshments.

FRANCES FISHER, *Secretary.*

AT VICTORIA

October 27, 1933.—At this regular meeting some 50 members and friends were present.

A five minute talk on Sir William Herschel and his work was given by H. E. Moore.

The lecturer of the evening was Dr. J. A. Pearce, who gave an address on "New Stars." The lecture was illustrated with tables and photographs of several novae and their spectra.

November 17, 1933.—About 65 were present.

Following a five minute talk by Gordon Shaw on "Light Waves," Dr. F. S. Hogg addressed the meeting on "Meteors, our Visitors from Space."

December 8, 1933.—Annual meeting. The president, P. H. Hughes, being in the chair and some 48 present, scrutineers of the ballots in the election of officers for 1934, were appointed. After the usual business the president addressed the meeting on the activities of the Centre during the past year and kindly offered to members his 3 inch alt-azimuth refractor for use in observational work.

Messrs R. Peters, G. E. Grist and R. J. Jameson were elected to membership.

Reports of the Treasurer and Secretary were then presented and unanimously adopted.

The Scrutineers then presented the results of the election of officers for 1934, as follows:—

Honorary President—James Duff, M.A.

President—H. Boyd Brydon.

Vice-Presidents—Charles Hartley, M.A., F. S. Hogg, Ph.D.

Secretary—H. E. Moore, M.A.

Council—G. Browne-Cave, W. Burton, T. J. Greenway, F.I.C., W. R. Hobday, W. F. Holdridge, and Lt. Comm. R. H. Tingley, R.C.N.

On invitation of the retiring president the new president then took the chair, and after briefly thanking the members for the honour accorded him introduced Lt.-Comm. F. L. Houghton, R.C.N., who gave a most instructive address on astrophysics, entitled "Astronomy and the Atom." Numerous specially prepared tables and diagrams together with several lantern slides were used in illustrating the points discussed. Following a short discussion, during which the lecturer was heartily congratulated on his excellent presentation of his subject, Comm. Houghton demonstrated spectra of neon and of mercury and argon which proved of great interest, nearly everyone availing themselves of the opportunity to see these spectra.

Votes of thanks to the retiring officers and to the press were carried by acclamation.

In closing the meeting the president spoke of the strenuous times the Centre

had been passing through and said that while there seemed to be some improvement in conditions, the success of the coming year depended not only on the newly elected officers, who were only the machinery appointed to carry on the routine work of the Centre, but on every member. The new year must be made successful by the co-operation of all.

H. Boyd Brydon, *Secretary-Treasurer.*

AT VANCOUVER

November 14, 1933.—The nineteenth regular meeting was held at the University of British Columbia. The President, Mr. Teasdale, was in the chair.

Mr. Paul Sykes reported on the Meteor Society.

The speaker for the evening, Professor M. Y. Williams, of the Department of Geology of the University of British Columbia, was then introduced by Mr. Teasdale.

Speaking on the topic "The Building of the Earth", Dr. Williams began by contrasting the fields of operation of the astronomer and the geologist. The question of the origin of the earth and the validity of the Planetesimal Hypothesis advanced by Chamberlin belonged to the realm of the astronomer, and as a geologist Dr. Williams established his starting-point at the earliest records of the rocks.

A small piece of gneiss from the Lake Superior region was believed to belong to the original crust of the earth, but it is very doubtful whether any of this crust remains. The oldest rocks are found in Canada and in the Scandinavian countries. There are schists which were apparently formed in the same manner as that of more recent types. Earlier rocks of volcanic origin the basalts are found also in Russia, and the age of these intrusive rocks, from their radioactivity, is placed at 1,800 million years.

The first geological period, the Archaeozoic Era, occupied about one-third of total geological time, and was characterized by the existence of schists and quartzites. It came to a close after about 7,500,000 years marked by great mountain-building. Geological eras are defined in terms of a cycle of changes, the laying down of sediments in shallow seas, fluctuation of land and sea-levels, terminating in mountain building.

The second great era, the Proterozoic, was approximately as long as the first. The iron-bearing formations around Lake Superior were laid down during this period, and many important mineral deposits formed. Here also we have the first evidences of life in the form of ancient sponges, and worm-burrows are also to be observed. Probably much more life existed than is shown by the fossils—the red color of many of the rocks indicating that plenty of oxygen was available.

Further mountain building at the end of this era led to the formation of the Cobalt series, and silver and gold bearing rocks appeared. Apparently there was a period of temporary cold weather and glaciation since the formations of some of these rocks indicate the effects of glaciers.

The continents have maintained much the same grouping throughout the ages, although in the past they were much larger and not so high. In this connection the speaker pointed out that although there is a difference of 65,000 feet in elevation between the top of Mt. Everest and the greatest depth of the ocean, this height is negligible compared to the size of the earth, and the irregularities in the earth's surface are smaller in proportion than the grooves on a billiard ball.

There now dawned a new era of great importance, the Palaeozoic, the age of life. In length about 330 million years, it produced life with great profusion, as evidenced by the thousands of fossils which have been obtained. These are chiefly of marine animals which developed in the wide and shallow seaways.

The era as a whole may be divided into seven periods separated by mountain building which was succeeded by a spreading of the seas over the land. Life was largely destroyed as the seas receded and those forms which persisted were given a chance to develop when the water returned.

The record shows at first no vertebrates, but later fishes developed and land flora which grew to forests in the swamps and provided for the formation of the coal deposits. Amphibians inhabited the forests of the Carboniferous Period and there were a few ancient reptiles. The mountain building which closed this period raised the Appalachian Mountains.

During the Mesozoic Era, 110 millions of years in length, the coast range from here to Alaska was built up and the coal deposits of British Columbia were laid down. This was the age of dinosaurs, common in Alberta and perhaps also in British Columbia. At the close of the period early mammals began to develop.

At this stage the Rocky Mountains were produced, and the last of the shallow seas disappeared from the central part of North America.

The Cenozoic or Tertiary Era lasted 60 millions of years and during this time the sediments which form Point Grey were laid down by an older river than the Fraser. Forests showed more and more the modern types of tree and the brain capacity of the mammals increased about five times. During this period the remarkable development in the size of the horse took place. At its close the Sierra Nevada mountains and coast ranges appeared and the coastal volcanoes around the Pacific were extremely active. The average level of land was raised two thousand feet higher than at present.

These conditions helped to bring about the Great Ice Age from which we are just emerging at the present day. This has lasted for a long time with successive advances and retreats of the vast ice layer which covered a large part of North America and Europe and also parts of Australia.

The effect on life was that the animals were driven south and thousands died. In Europe one form of life developed which could survive the hard times and that was man. This points a moral that life in its higher forms has made the greatest development while struggling with adverse conditions.

The lecturer then showed a series of excellent slides depicting the early geography of North America and colored reproductions of early landscapes and animals.

WILLIAM URE, *Recorder.*

The Royal Astronomical Society of Canada

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